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127

THE

MINERALOGICAL MAGAZINE

AND

Journal of

The Mineralogical Society

(*INSTITUTED FEBRUARY 3, 1876.*)

WITH A SEPARATELY-PAGED APPENDIX OF

MINERALOGICAL ABSTRACTS

EDITED BY L. J. SPENCER, F.R.S.

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DE
MINÉRALOGIE ET PÉTROGRAPHIE

Published by the Mineralogical and Petrographical Society of Switzerland. Numbers are issued semi-annually and contain about 200 pages. Among the contributors are all Swiss mineralogists and petrographers and the mineralogical institutes of the Swiss Universities. The papers cover the whole field of crystallography, mineralogy, and petrography with special reference to the Alps.

Subscription Rates.

Free to members of the Mineralogical and Petrographical Society of Switzerland (annual subscription to the Society 20 frs., applications for membership to be addressed to Prof. J. JAKOB, Mineralogical Institute, Sonneggstrasse 5, Zürich 6). Subscriptions for non-members (two issues) 25 frs. Remittances to be addressed to

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VOL. 21–120–1

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PROCEEDINGS

OF THE

MINERALOGICAL SOCIETY

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., January 18, 1927, *at* 4.30 *p.m.*

Sir Henry A. Miers, F.R.S., Past-President, in the Chair.

The resignation of Mr. T. C. F. Hall was accepted.

Dr. Norman Levi Bowen and Mr. Sidney William Wooldridge were provisionally elected Ordinary Members of the Society.

The audited accounts and balance-sheet for the year ending December 31, 1926, submitted by the Treasurer, were approved. Audited accounts and balance-sheet of the Jubilee Entertainment Fund and an abridged statement for publication were also submitted and approved.

A vote of thanks to the Treasurer for his presentation to the Society of the Jubilee Record Album was passed.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., January 18, 1927, *at* 5.30 *p.m.*

Prof. Harold Hilton, Vice-President, in the Chair.

Twenty-three Members and two Visitors were present.

The elections of Dr. N. L. Bowen and Mr. S. W. Wooldridge as Ordinary Members of the Society were confirmed.

The following papers were read :—

1. The temperature-range of formation of tourmaline, rutile, brookite, and anatase in the Dartmoor granite : by Dr. A. Brammall and Dr. H. F. Harwood (p. 205).

2. Notice of an occurrence of niccolite and ullmannite at the Settlingstones mine, Fourstones, Northumberland; and of serpierite at Ross Island mine, Killarney, Co. Kerry: by Mr. Arthur Russell (p. 383).

Micro-sections of a theralite from Rapa Island were exhibited by Mr. Campbell Smith, and specimens in illustration of his paper by Mr. Russell.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., March 15, 1927, *at* 4.30 *p.m.*

Prof. W. W. Watts, F.R.S., President, in the Chair.

Mr. Edward Leslie Gilbert Clegg, Prof. Tsutomu Ogura, and Mr. William Alfred Wooster were provisionally elected Ordinary Members of the Society.

A proposed exchange of advertisements made by the Swiss Mineralogical Society was accepted.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., March 15, 1927, *at* 5.30 *p.m.*

Prof. W. W. Watts, F.R.S., President, in the Chair.

Twenty Members and three Visitors were present.

The elections of Mr. E. L. G. Clegg, Prof. T. Ogura, and Mr. W. A. Wooster as Ordinary Members of the Society were confirmed.

The following papers were read:—

1. A melilite-spurrite-Ca_2SiO_4 assemblage from Larne (Co. Antrim): by Dr. C. E. Tilley.

2. Alkali-rocks from Nimrud volcano, Armenia: by Dr. G. T. Prior.

3. Rotating crystal X-ray photographs: by Mr. G. Greenwood (p. 258).

4. Biographical notices of mineralogists recently deceased (third series): by Dr. L. J. Spencer (p. 229).

Dr. Felix Oswald gave a description of the Nimrud volcano illustrated by lantern-slides, and specimens and microscope slides were exhibited by Dr. Tilley and Dr. Prior in illustration of their papers.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., June 14, 1927, *at* 4 *p.m.*

Prof. W. W. Watts, F.R.S., President, in the Chair.

The deaths of Prof. Gustav von Tschermak, Honorary Member, and of Dr. Richard Pearce and Dr. Jorge Belmiro Araujo Ferraz, Ordinary Members, were announced. The Foreign Secretary was instructed to send a letter of sympathy to the family of Prof. Tschermak.

The following were provisionally elected Ordinary Members of the Society: Mr. Nérée Boubée, Lieut.-Colonel Basil Elmsley Coke, Miss Gertrude Lilian Elles, Mr. Charles Stansfield Hitchen, Mr. Charles Mathews, and Dr. Charles Taylor Trechmann.

The following changes in the list of Officers and Council were approved for recommendation to the Members of the Society: President—Dr. G. T. Prior, in place of Prof. W. W. Watts; Vice-President—Sir John S. Flett, in place of Prof. Harold Hilton; General Secretary—Mr. W. Campbell Smith, in place of Dr. G. T. Prior; Ordinary Members of Council—Mr. A. J. Bull, Prof. C. G. Cullis, Prof. Harold Hilton, and Dr. W. F. P. McLintock, in place of the four retiring Members of Council, Mr. A. F. Hallimond, Mr. J. A. Howe, Mr. W. Campbell Smith, and Dr. C. E. Tilley.

It was decided to hold four meetings next year on the following dates: Tuesdays, January 17, March 20, June 12, and November 6, 1928.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., June 14, 1927, *at* 5.30 *p.m.*

Prof. W. W. Watts, F.R.S., President, in the Chair.

Twenty-eight Members and three Visitors were present.

The elections of Mr. N. Boubée, Lieut.-Colonel B. E. Coke, Miss G. L. Elles, Mr. C. S. Hitchen, Mr. C. Mathews, and Dr. C. T. Trechmann as Ordinary Members of the Society were confirmed.

A kinematograph film, which had been taken by Dr. Harry von Eckermann of episodes during the Northern Excursion of the Jubilee Celebrations in 1926, was shown on the screen.

The following papers were then read :—

1. On the atomic volume relations in certain isomorphous series: by Mr. A. F. Hallimond (p. 277).

2. Petrology of the Bodmin Moor granite (eastern part), Cornwall: by Dr. P. K. Ghosh (p. 285).

3. On the distribution of purple zircon in British sedimentary rocks: by Prof. P. G. H. Boswell (p. 310).

4. On β-quartz twins from some Cornish localities: by Dr. J. Drugman (p. 366).

5. The separation of manganese in rock analysis: by Mr. E. V. Holt and Dr. H. F. Harwood (p. 318).

6. Corundum twins from Transvaal: by Dr. L. J. Spencer (p. 329).

Specimens were exhibited by Dr. Drugman in illustration of his paper.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., November 1, 1927, *at* 4 *p.m.*

Prof. W. W. Watts, F.R.S., President, in the Chair.

The death of Prof. Archibald Liversidge, one of the earliest members of the Society, was announced, and the Secretary was instructed to send a letter of sympathy to his sister, Mrs. C. S. Balfern.

Mr. Frederick Allan Bannister and Mr. William Richard Storr were provisionally elected Ordinary Members of the Society.

The Treasurer reported the receipt of a legacy of £200 (less duty) bequeathed to the Society under the Will of the late Sir William Phipson Beale, Bart., Past-President, who died in April 1922. This bequest became payable on the death of Lady Beale, which occurred in January last.

Dr. H. H. Thomas and Mr. H. Dewey were appointed auditors of the accounts for the year ending December 31, 1927.

The draft Annual Report of Council submitted by the Secretary was read and approved.

GENERAL (ANNIVERSARY) MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., November 1, 1927, *at* 5.30 *p.m.*

Prof. W. W. Watts, F.R.S., and later Dr. G. T. Prior, F.R.S., President, in the Chair.

Twenty-five Members and five Visitors were present.

The President nominated Prof. W. G. Fearnsides and Mr. J. Broadhead to act as scrutineers of the voting-papers for the election of Officers and Council. The scrutineers reported that forty-one voting-papers had been returned to the Secretary, and that the list as nominated by the Council was approved, namely :—

President. Dr. G. T. Prior, M.A., D.Sc., F.R.S.

Vice-Presidents. Sir Thomas H. Holland, K.C.S.I., K.C.I.E., D.Sc., F.R.S.

Sir John S. Flett, K.B.E., M.A., LL.D., D.Sc., F.R.S.

Treasurer. F. N. Ashcroft, M.A., F.G.S., F.C.S.

General Secretary. W. Campbell Smith, M.C., M.A., F.G.S.

Foreign Secretary. J. W. Evans, C.B.E., D.Sc., LL.B., F.R.S.

Editor of the Journal. L. J. Spencer, M.A., Sc.D., F.R.S.

Ordinary Members of Council.

Prof. P. G. H. Boswell, O.B.E., D.Sc., F.G.S.
T. Crook, A.R.C.Sc.I., F.G.S.
L. Hawkes, D.Sc., F.G.S.
H. H. Thomas, M.A., Sc.D., F.R.S.
Prof. H. L. Bowman, M.A., D.Sc., F.G.S.
Prof. W. T. Gordon, M.A., D.Sc., F.R.S.E.
H. F. Harwood, M.Sc., Ph.D., A.I.C.
G. F. Herbert Smith, M.A., D.Sc., F.G.S.
A. J. Bull, M.Sc., F.Inst.P., F.G.S.
Prof. C. G. Cullis, D.Sc., F.G.S.
Prof. Harold Hilton, M.A., D.Sc.
W. P. F. McLintock, D.Sc., F.G.S.

The elections of Mr. F. A. Bannister and Mr. W. R. Storr as Ordinary Members of the Society were confirmed.

A vote of thanks to the Geological Society for the use of their rooms, proposed by Dr. Tutton and seconded by Mr. Arthur Russell, was carried.

The General Secretary then read the following

ANNUAL REPORT OF COUNCIL.

During the Session 1926–7 four ordinary meetings have been held, by kind permission, in the apartments of the Geological Society, Burlington House, London, W., at which seventeen papers were read. An interesting feature of the June meeting was the exhibition of a kinematograph film, which had been taken by Dr. Harry von Eckermann, of episodes during the Northern Excursion of the Jubilee Celebrations in 1926.

Four numbers of the Journal (nos. 115–118), containing eighteen papers and 614 abstracts, have been issued quarterly. No. 115 for December, 1926, is the Jubilee Number, and contains a detailed account of the Jubilee Celebrations, including the Presidential Address dealing with the fifty years work of the Society. During the Session has been published also the General Index to vols. XI–XX (1895–1925), for the compilation of which the Society has once more to express its great indebtedness to the Editor. It is preceded by a Topographical Index and contains the 1506 mineral names which have appeared in Dr. Spencer's ten 'Lists of new mineral names.' An album to contain the letters and addresses of congratulation, &c., on the occasion of the Jubilee has been presented to the Society by Mr. F. N. Ashcroft.

The balance-sheet for the year ending December 31, 1926, showed that the financial position of the Society was sound. The assets (exclusive of the Library and stock of the publications) amounted to £1,574 18*s.* 9*d.*, with no liabilities. The value of the stock invested in the names of the Trustees of the Society was on that date £1,256 3*s.* 9*d.*, corresponding to £24 12*s.* 0½*d.* for each Life-Member. A sum of £100 was granted by the Royal Society from the Government Publication Fund in aid of the publication of 'Mineralogical Abstracts'. On the death of Lady Beale this year the Society received the £200 (less duty) legacy bequeathed by Sir William Beale.

During the Session the Society has lost by resignation, one Ordinary Member; by removal for non-payment of subscription, one Ordinary Member; and by death, one Honorary Member, viz. Prof. Gustav von Tschermak, and three Ordinary Members, viz. Dr. Jorge Belmiro Araujo Ferraz, Prof. Archibald Liversidge, and Dr. Richard Pearce. Three Honorary Members and sixteen Ordinary Members have been elected. The total number of Members on October 31, 1927, was 202, of whom twelve are Honorary. Of the Ordinary Members fifty-one are Life-Members.

During the Session Dr. Prior has continued to represent the Society on the Federal Council of Pure and Applied Chemistry, and Dr. Spencer and Dr. Herbert Smith on the 'Publications' and 'Miscellaneous' Committees respectively of the Imperial Institute.

The Council has to congratulate the Society on its continued scientific activity and prosperity.

On the motion of Mr. F. H. Butler, seconded by Mr. R. A. A. Johnston, the Report was adopted.

Before vacating the Chair, Prof. Watts made reference to the eighteen years' service of the retiring Secretary, to which Dr. Prior, on taking the Chair, replied.

The following papers were then read:—

1. Specific gravities of minerals: an index of some recent determinations: by Dr. L. J. Spencer (p. 337).

2. South African occurrences of willemite. Fluorescence of willemite and some other zinc minerals in ultra-violet rays: by Dr. L. J. Spencer (p. 388).

3. A study of bauxite: by Dr. T. V. M. Rao (p. 407).

4. On the biotite-bearing greenstones and on a rhyolitic pumice in the metamorphic aureole of the Falmouth granite: by Dr. P. K. Ghosh (p. 436).

In illustration of his paper Dr. Spencer demonstrated the striking luminescent effects shown by willemite, fluorite, and some other minerals when exposed to ultra-violet rays in the 'analytic quartz lamp', kindly lent for the occasion by the British Hanovia Quartz Lamp Co., Ltd.

MINERALOGICAL

ABSTRACT OF RECEIPTS AND PAYMENTS

Receipts.	£ s. d.	£ s. d.
		GENERAL PUR-
By Balance brought forward from 1926—		
1. At Bankers:		
(*a*) Current Account	9 13 3	
(*b*) Deposit Account	100 0 0	
2. In Office	0 7 9	
		110 1 0
Annual Subscriptions—		
1. Current year	134 8 0	
2. Arrears	10 10 0	
3. Advance	8 10 11[1]	
		153 8 11
Entrance Fees		13 13 0
Composition Fees		78 15 0
Sale of Publications—		
1. By Publishers:		
(*a*) Simpkin, Marshall, Hamilton, Kent & Co., Jan.–Feb. 1926 (£30 0*s.* 0*d.*, less trade discount and commission £3 15*s.* 0*d.*)	26 5 0[2]	
(*b*) Oxford University Press, April 1, 1926–March 31, 1927 (Subscription Copies £262 0*s.* 0*d.*, and other sales £170 1*s.* 6*d.*, less trade discount and commission £122 3*s.* 10*d.*, and postage and packing £8 1*s.* 3*d.*)	301 16 5[2]	
2. By Custodian of Stock, 1927 (£37 14*s.* 3*d.*, less trade discount £3 9*s.* 11*d.*, and distribution charges £1 3*s.* 11*d.*)	33 0 5	
		361 1 10
Advertisement Fees (£17 10*s.* 6*d.*, less commission £3 10*s.* 1*d.*)		14 0 5
Interest on Investments—		
1. £1,505 5% War Loan 1929–47 Inscribed Stock	63 5 0	
2. £105 4% Consolidated Loan 1957 Inscribed Stock	2 2 0	
3. £50 4% Funding Loan 1960–90 Inscribed Stock	2 0 0	
4. £50 5% War Bonds 1927 Registered	0 16 10	
		68 3 10[3]
Deposit Interest		7 6 0
Small Receipts		0 3 0
Bequest under the Will of the late Sir William P. Beale, Bart., Past-President (£200, less Legacy Duty £20)		180 0 0
Transferred from Jubilee Entertainment Fund Account (final instalment)		7 19 11
		£994 12 11

[1] Includes a part payment. [2] *Vide* note following the Balance-sheet.
[3] Except in the case of the 5% War Bonds which were converted into £62 2*s.* 6*d.* 4% Consolidated Stock in February, 1927, the holdings shown are those on December 31, 1927, not those on which interest was received.

SOCIETY.

FOR THE YEAR ENDING DECEMBER 31, 1927.

POSES ACCOUNT.

Payments.	£ s. d.	£ s. d.
To Printing and distributing the Mineralogical Magazine Nos. 116-119 inclusive (Oxford University Press)—		
1. Printing	284 8 6	
2. Illustrations	31 8 6	
3. Authors' Copies	26 18 6	
6. Distribution Charges	12 4 0	
		354 19 6
Miscellaneous Printing (not annual)—		
1. Prospectus (including distribution charges)	26 17 6	
2. Notices *re* special numbers of the Magazine	0 13 6	
3. Sheets of printed numbers and letters for Editor (stock of)	0 15 0	
		28 6 0
Printing and distributing notices of Meetings and other annual miscellaneous printing		14 12 6
Expenses at Meetings, 1927—		
1. Operator of lantern	2 2 0	
2. Porter	1 0 0	
3. Hire of Kinematograph Projector (including Operator)	2 12 6	
		5 14 6
Care of Stock of Publications, 1927 (J. Mugford)		1 1 0
Editor's Honorarium		25 0 0
Postage—		
1. Hon. Secretary	0 8 4	
2. Editor	2 4 0	
3. Hon. Treasurer (not charged)		
		2 12 4
Stationery (renewal of stock of)		2 3 6
Bank charges and other small items		0 1 6
Investments (including composition fees and the bequest received during the year), purchase of £355 5% War Loan Inscribed Stock and £42 17*s.* 6*d.* 4% Consolidated Loan Inscribed Stock, commissions and stamps		401 4 0
Balance, December 31, 1927—		
1. At Bankers :		
(*a*) Current Account	18 14 10	
(*b*) Deposit Account	140 0 0	
2. In Office	0 3 3	
		158 18 1
		£994 12 11

Examined and compared with vouchers and found correct.

HENRY DEWEY
HERBERT H. THOMAS } Auditors.

January 4, 1928. F. N. ASHCROFT, Hon. Treasurer.

LIBRARY FUND

Receipts.	£	s.	d.
By Balance brought forward from 1926—			
At Bankers	13	9	0
	£13	9	0

BALANCE

DECEMBER

Liabilities.	£	s.	d.
Excess of Assets over Liabilities	1961	19	7
	£1961	19	7

ACCOUNT.

PAYMENTS.

	£	s.	d.
To Binding of Periodicals	6	10	0
Balance, December 31, 1927—			
At Bankers	6	19	0
	£13	9	0

Examined and compared with vouchers and found correct.

HENRY DEWEY
HERBERT H. THOMAS } Auditors.
F. N. ASHCROFT, Hon. Treasurer.

January 4, 1928.

SHEET.

31, 1927.

ASSETS.	£	s.	d.	£	s.	d.
Balances—						
I. General Purposes Account:						
1. At Bankers:						
(*a*) Current Account	18	14	10			
(*b*) Deposit Account	140	0	0			
2. In Office	0	3	3			
				158	18	1
II. Library Fund Account:						
At Bankers				6	19	0
Sale of Publications—						
By Publishers, April 1 to Dec. 31, 1927 (estimate)				120	0	0
Advertisement Fees (estimate)				15	0	0
Investments at Broker's Valuation—						
1. £1,505 5% War Loan Inscribed Stock at 101¼	1523	16	3			
2. £50 4% Funding Loan Inscribed Stock at 88¼	44	2	6			
3. £105 4% Consolidated Loan Inscribed Stock at 85¾[1]	90	0	9			
				1657	19	6
Arrears of Annual Subscriptions, valued at				3	3	0
				£1961	19	7

The Stock of Publications and the value of the Library are not included in the above assets.

January 11, 1928. F. N. ASHCROFT, Hon. Treasurer.

[1] *Ex* dividend payable February 1, 1928.

Note re Sale of Publications.

The Accounts for the past year have been materially affected by the change in the Society's publishers (which took place early in 1926), owing to the institution at that time of a subscription rate for the four numbers issued each year, and to the new publishers' financial year ending on March 31 instead of on December 31. Some explanation, therefore, of the figures for the sales by the publishers seems required.

Under the new scheme all payments at the subscription rate are received by the publishers in advance, and very largely during the first three months of the year. This means an antedating of the Society's receipts from that source, with the result that last year the Society received the proceeds of such payments for the numbers issued during both 1926 and 1927[1] at the same time (Item, Sale of Publications 1 *b* in the Accounts). Stated in figures the net receipts during 1927 were thus greater than they would otherwise have been by from £95 to £100. The position is now stabilized and this duplication will not recur.

The estimates of the receipts from sales by the publishers given in the Balance Sheets have also been affected. Prior to the change, as in the Balance Sheet for December 31, 1925, the figure therefor was the amount expected to be received from the publishers during 1926 for sales effected during 1925, and also represented the total the Society would receive during the year from that source. On the other hand, the estimate in the Balance Sheet for December 31, 1927, relates to the publishers' receipts from ordinary sales and at the subscription rate during the period April 1 December 31, 1927, in addition to which the Society will receive during the year the receipts from these sources for the period January 1–March 31, 1928.

F. N. ASHCROFT, Hon. Treasurer.

[1] Exclusive of subscription payments received by the publishers after March 31, 1927.

JUBILEE ENTERTAINMENT (VOLUNTARY) FUND ACCOUNT.

Abstract of Receipts and Payments during 1927.

Receipts.	£	s.	d.	Payments.	£	s.	d.
By Balance brought forward from 1926 . . .	15	8	1	To Expenditure . . .	7	8	2
				Transferred to the General Purposes Account . .	7	19	11
	£15	8	1		£15	8	1

Examined and compared with vouchers and found correct.

W. F. P. McLINTOCK } Auditors.
A. F. HALLIMOND }

February 18, 1927.

F. N. ASHCROFT, Hon. Treasurer.

Note.—A detailed statement was issued to the subscribers to the Fund when the account was closed on February 18, 1927.

THE MINERALOGICAL MAGAZINE

AND

JOURNAL OF

THE MINERALOGICAL SOCIETY.

No. 120. March, 1928. Vol. XXI.

Potarite, a new mineral discovered by the late Sir John Harrison in British Guiana.

By L. J. Spencer, M.A., Sc.D., F.R.S.

Keeper of Minerals in the British Museum (Natural History).

[Read January 17, 1928.]

THE untimely death of Sir John B. Harrison[1] on February 8, 1926, just as he was returning home after over forty-six years' service in the West Indian colonies, unfortunately prevented the publication by him of a complete account of the interesting new mineral which, as a result of much patient chemical work, he had discovered in British Guiana. As he had corresponded with me on this matter since April, 1924, and further, as this is the same mineral that I had myself erroneously described as 'allopalladium',[2] I feel it my duty to place on record the full facts so far as can now be ascertained.

I had suggested that the new mineral might be named after Sir John Harrison, but this he objected to; and, in consultation with the Governor of British Guiana, he proposed the name potarite (letter of April 3, 1925), but he did not himself record this name in print. In 1925, at his

[1] Sir John Burchmore Harrison (1856–1926). Obituary notices in Bull. Geol. Soc. Amer., 1927, vol. 38, pp. 45–52, with portrait and bibliography; and Min. Mag., 1927, vol. 21, p. 234.

[2] L. J. Spencer, Allopalladium from British Guiana. Min. Mag., 1924, vol. 20, pp. 217–219.

suggestion, and with the approval of the Governor, specimens of the new mineral labelled as potarite, from the small stock totalling about 40 grams, were generously presented by the Government of British Guiana to various scientific collections, namely to the British Museum, the Mineralogical Museum of Cambridge University, the Muséum d'Histoire Naturelle in Paris, and the United States National Museum in Washington, D.C. The nugget weighing 3·2 grams sent to the Paris museum was shown by Prof. A. Lacroix at a meeting of the French Mineralogical Society on January 14, 1926, and the name potarite appeared in the report of that meeting.[1] It also appeared in the annual reports of the Cambridge Museums [2] and of the United States National Museum.[3] But the earliest printed record of the name appears to be in 'The West India Committee Circular', London, October 22, 1925 (p. 429). The name potarite is also incidentally mentioned by Mr. H. J. C. Conolly, Economic Geologist and Mineralogist of British Guiana, in his 'Report of the preliminary survey of the Mazaruni and Puruni diamond fields, British Guiana',[4] and by Dr. G. F. Kunz in his annual report on platinum metals.[5]

The publications of Sir John Harrison relating to this mineral appeared as Government Notices in the 'Official Gazette' of British Guiana under the titles:

'An occurrence of palladium and rhodium in British Guiana.' (May 3, 1924, no. 181, 2 pp.)

'The occurrence of palladium amalgam—palladium mercuride—in British Guiana.' With C. L. C. Bourne. (February 28, 1925, no. 71, 3 pp.)

Copies of these papers were sent out by Sir John Harrison, and notices of them appeared as abstracts in certain scientific journals,[6] though without any mention of the name potarite.

The name potarite is from the Potaro river, a left tributary of the Essequibo in British Guiana, the only source of the mineral so far known

[1] Bull. Soc. Franç. Min., 1926, vol. 49, p. 5.

[2] Cambridge University Reporter, March 17, 1926, vol. 56, p. 778.

[3] Report of the United States National Museum for the year ended June 30, 1926, 1927, pp. 84, 130.

[4] London, [1926], pp. 6, 7 [Min. Abstr., vol. 3, p. 438]. From this source the name potarite appeared in Bull. Imp. Inst. London, 1927, vol. 24 (for 1926), p. 776 (compare also p. 767).

[5] G. F. Kunz, Mineral Industry, New York, 1927, vol. 35 (for 1926), p. 548.

[6] Journ. Chem. Soc. London, 1925, vol. 128, Abstracts, pt. ii, pp. 592 593; Chem. News, London, 1925, vol. 131, pp. 88–89, 1926, vol. 132, p. 124; Chem. Abstr. (Amer. Chem. Soc.), 1925, vol. 19, p. 3075; Amer. Min., 1925, vol. 10, p. 333; Min. Abstr., 1926, vol. 3, p. 4.

being in the neighbourhood of the gorge below the Kaieteur falls.[1] A single small grain of platinum was found there by Mr. J. C. Menzies in 1923,[2] and soon afterwards, while prospecting near Oewang and Tukeit in the same neighbourhood, he found other minute white metallic grains. These were incorrectly described in 1924 by me as 'allopalladium' and by Sir John Harrison as palladium and rhodium. Since then a white metal has been found by several of the diamond-washers in relatively larger, though still very scanty, amounts in the Kangaruma district, situated about 16 miles from the place of the first find, and also in the Amatuk district.[3] This supplied Sir John with more material for investigation and he was able definitely to establish the mineral as a compound of palladium and mercury.

With the very small amount of material (a few milligrams) at first available it is not surprising that mercury was overlooked. In order to save at least some of the material for preservation in the collection, I had applied only micro-chemical tests. In one case, however, Sir John had noticed the presence of mercury, but he concluded that this had been introduced by the diamond-washers when saving gold, which is also present in the diamond-bearing gravels. Mercury had not then been recorded from British Guiana, but curiously, while engaged on this work in December, 1924, Sir John had brought to him a small specimen of cinnabar[4] from a lateritic clay in the Kurupung district on the Mazaruni river (about 100 miles to the north-west). Further, it is to be noted that, as Sir John afterwards found out, the diamond-washers had in some cases heated the metal, thinking at first that they had a gold-amalgam, and afterwards testing the fusibility before the blowpipe for platinum. The result was that some of the material had lost much of its mercury and was not in a natural condition.

The spurting noticed on the surface when the metal was heated was at first ascribed to the liberation of occluded hydrogen and other gases in the palladium. With larger fragments a more exact determination of the specific gravity was possible, and values ranging from 13·48 to 16·11 were

[1] The famous Kaieteur falls have a vertical drop of 741 feet, nearly five times the height of Niagara.

[2] L. J. Spencer, Euclase and platinum from diamond-washings in British Guiana. Min. Mag., 1924, vol. 20, pp. 186–192.

[3] The locality of the specimen sent to the Paris museum is given as Amu creek (Bull. Soc. Franç. Min., 1926, vol. 49, p. 5).

[4] A similar occurrence of cinnabar in laterite has recently been described from Dutch Guiana by C. Palache, Amer. Min., 1927, vol. 12, p. 188 [Min. Abstr., vol. 3, p. 359].

obtained, much higher than that of palladium (11·97). The average specific gravity from eleven determinations was 14·8. It was thought that perhaps this difference might be accounted for by the two modifications of palladium—the ordinary malleable cubic palladium and the alleged brittle hexagonal allopalladium. Experiments were therefore made with the idea of converting the latter into the former by heating up to temperatures of about 1400° C. But when the specific gravity of the heated material was determined it was found that there had been a considerable loss in weight. This was puzzling and was at first ascribed to osmium, but very soon this loss, ranging from 54·4 to 65·2 %, was found to be due to mercury. After being purified by two distillations, the mercury expelled from potarite was found to have a density of 13·6. The palladium left after repeated heatings was porous, with specific gravity 10·0–11·0; but after hammering the metal, the specific gravity was determined as 11·33–11·9.

The actual determinations given in Sir John Harrison's second report are as follows, the material being heated in vessels of silica-glass:

	Weight in grams.	Sp. gr.	Percentage loss in weight (Hg).
No. 1, fragment, heated for successive periods at increasing temperatures up to nearly 1400° C.—			
Original	0·529	15·82	—
After 1st heating	0·325	14·13	38·6
,, 2nd ,,	0·290	14·08	45·2
,, 3rd ,,	0·220	13·92	58·4
,, 4th ,,	0·190	11·31	64·1
No. 2, several small fragments, heated over blast-lamp for half-hour periods.—			
Original	0·978	15·00	—
After 1st heating	0·649	14·11	33·6
,, 2nd ,,	0·410	10·78	58·1
,, 3rd ,,	0·340	10·39	65·2
and hammering	—	11·33	—
No. 3, fragment, heated over blast-lamp for one-hour periods.—			
Original	1·303	13·48	—
After 1st heating	0·927	12·20	28·8
,, 2nd ,,	0·594	10·42	54·4
,, 3rd ,,	0·594	—	54·4
and hammering	—	11·4	—
No. 4, nugget, heated over Méker burner (about 1400° C.) for one-hour periods.—			
Original	2·197	15·15	—
After 1st heating	1·102	10·02	49·9
,, 2nd ,,	1·007	10·71	54·2
,, 3rd ,,	1·001	11·0	54·4
,, 4th ,,	0·990	11·0	54·9
and hammering	—	11·9	—

These results were collected together in the following manner:

	Sp. gr.	Pd (with traces of Rh, Pt, Au).	Hg.
1.	15·82	35·9	64·1
2.	15·00	34·8	65·2
3.	13·48	45·6	54·4
4.	15·15	45·1	54·9

As noted above, some at least of the specimens had been heated before being received for scientific examination, and we may therefore take Sir John's higher values as representing the true mercury percentage. But there is an inexplicable variation in the specific gravity between (1) and (2), as also between (3) and (4), although these are in pairs apparently the same in chemical composition. The high values of the specific gravity up to 16·11 (except 13·48) also present an anomaly, for they are much higher than the density of either of the components, namely 11·97 for palladium and 13·60 for mercury (or 14·19 for solid mercury). This high degree of 'condensation' was puzzling to Sir John Harrison, but it no doubt indicates that the mineral is a definite compound of palladium and mercury rather than an amalgam. The formula PdHg corresponds with the percentage composition Pd 34·7, Hg 65·3, agreeing closely with the determined values (1) and (2). The close agreement between (3) and (4) perhaps suggests another compound Pd_3Hg_2, which corresponds with Pd 44·4, Hg 55·6 %.

A remarkable fact is the difficulty with which the mercury is expelled from the mineral, prolonged and repeated heating at a high temperature being necessary. Also, as found by Sir John Harrison, the mercury is not again readily taken up by the palladium. In his letter of January 9, 1925, he wrote:

> After we have driven off all the liquid metal from the alloy we cannot get the resulting porous palladium to readily take up a new supply of ordinary mercury.

and in his letter of November 25, 1925:

> In the hopes of artificially preparing an amalgam of palladium and mercury we left the porous fragment mentioned in my letter of January 9th in contact with an excess of mercury from the end of December, 1924, to November 12th, 1925. By the latter time the greater part of the porous palladium had dissolved in the large excess of mercury. We separated the liquid amalgam of palladium and mercury and we exposed it during many hours in an open silica tube surrounded by the vapour of boiling mercury. Very slowly indeed did the amalgam give off its excess of mercury, but finally we got a small quantity of a solid metal closely resembling in external properties our native palladium mercuride. The specific gravity of that solid metal was a little under 14·3, that

is, it had practically the density of solid mercury. We next analysed this artificial 'potarite' and found it to contain 36·8 % palladium and 63·2 % mercury. that is, this palladium mercuride had practically the composition Pd_2Hg_2. It is evident, however, that our artificial palladium mercuride has not the high state of condensation of the native mineral 'potarite'.

There appears to be little definite information in the literature about palladium amalgams (although these have been used in dentistry). In H. Watts's 'Dictionary of chemistry' (1865, vol. 3, p. 888) is stated: 'The amalgam containing Pd_2Hg is a grey powder, which, according to Berzelius,[1] does not give off its mercury below a white heat.'

The two largest nuggets (weighing about 12 and 11 grams) of potarite that have been found were kindly sent by Sir John Harrison in 1925 for my inspection, with the instruction to select one for the British Museum collection, the other to go to the Mineralogical Museum at Cambridge, as presents from the Government of British Guiana. Both these nuggets came from the diamond-washings in the Kangaruma district on the Potaro river. The smaller nugget is flatter, has a wider spread, and is brighter and more attractive in appearance. After some hesitation, I selected the slightly heavier nugget because it shows some crystalline structure on the surface.

This nugget weighs 12·074 grams and measures $2 \times 1\frac{1}{2} \times \frac{1}{2}$ cm. with an irregular indented outline. After scrubbing off a small amount of attached white clayey matter, the specific gravity was found by hydrostatic weighing to be 14·924, and when corrected $D_4^{20} = 14{\cdot}88$. The value given by Sir John Harrison in his second paper of February, 1925, is 14·78; and in his letter of April 15, 1925, he mentions that this nugget, acquired from Mr. W. A. Semple, had previously been offered to a jeweller, who admitted that he had heated it in places before the blowpipe to test its fusibility. This evidently accounts for the lower specific gravity as compared with the higher values noted above.

This specimen shows a somewhat indistinct columnar or fibrous structure, the columns being roughly across the plate and slightly divergent. On one side the columns terminate in a confused aggregate of octahedral points, and on the opposite surface there is a reticulate crystalline pattern. The appearance is that of a fragment of a crystalline crust that has

[1] J. Berzelius, Kongl. Vetensk. Acad. Handl. Stockholm, 1813, p. 205; translations in Journ. Chem. u. Physik (Schweigger), 1813, vol. 7, p. 67, and Annales de Chimie, 1813, vol. 87, p. 139. This amalgam contained 0·7073 gr. of palladium and 0·7277 gr. of mercury [50·7 %]; of the latter, 0·112 gr. was lost over a spirit-lamp, and 0·6157 gr. during exposure for $\frac{1}{2}$ hour to the highest white-heat.

become detached and only slightly water-worn. The octahedral points measure about 1 mm. across and the triangular facets are uneven and rounded, so that only approximate measurements could be obtained of the maximum light reflections on the goniometer. Values ranging from 63° to 77° suggest the octahedral angle 70° 32′. We can therefore conclude that the mineral is cubic in crystallization. Sir John Harrison had previously remarked on the indications of a crystalline and fibrous[1] structure in some of the nuggets and fragments; and after the material has been heated to expel the mercury the fibrous structure is still more evident.

Fig. 1. Diagrammatic section of nugget of Potarite.

The hardness is $3\frac{1}{2}$, the nugget scratching calcite but leaving a metallic mark on fluorite. A minute fragment broken off (rather than cut) with a knife was crushed to powder in an agate-mortar, but when rubbed it streaked out somewhat on the agate. The colour of the nugget and of the streak is silver-white with bright metallic lustre.

The suggestion was made by Sir John Harrison that I should test my 'allopalladium' from British Guiana for mercury. A minute fragment broken with a knife from the original material was found to be brittle when hammered on an anvil. The powder was placed in a glass bulb-tube and heated in a bunsen-flame, when I was surprised to see with a lens an abundant sublimate of minute globules of mercury. The result of this test has already been mentioned in a foot-note in the abstract[2] of Sir John Harrison's papers, at the same time remarking: 'The doubt now passes on to the original allopalladium from the Harz Mts.' The 'cleavage' was perhaps imaginary; in my note-book I had written: 'Examined under the metallographic microscope the fragments are silver-white with bright reflections as if from cleavages.' These perhaps represent the surfaces of separation between the several grains of the aggregate.

As mentioned in my previous paper, there is no specimen of allopalladium in the British Museum collection. There are, however, in the collection a number of specimens from Tilkerode, in the Harz Mts., under the species gold, clausthalite (PbSe), tiemannite (HgSe), naumannite, onofrite, and zorgite. All these I carefully searched with a magnifying lens for any possible allopalladium, though not with a 'compound

[1] He remarked that a fibrous structure has sometimes been described for the Brazilian native palladium, and he suggested that some of this might possibly be potarite.

[2] Min. Abstr., 1926, vol. 3, p. 5.

microscope' as was used by Zincken. Specimens of allopalladium from the collection of J. C. L. Zincken (1790–1862) are preserved in the Museum für Naturkunde in the University of Berlin, and Prof. M. Belowsky informs me that it requires some patience to find and see the minute scales of allopalladium on the gold of these specimens. Shortly before my inquiry a small scale of allopalladium had been sent from the Berlin collection to Prof. V. M. Goldschmidt of Oslo for examination in connexion with his work on the platinum metals. He tells me that the amount of material (a fraction of a milligram) is too small even to test for mercury by the new X-ray method of spectrum-analysis.

Palladium has undoubtedly been found in the Harz Mountains, although the 'allopalladium' seems to be doubtful. It was found during the chemical extraction of selenium[1] on a moderately large scale at Tilkerode[2] in the eastern Harz from the ores which carry gold, silver, lead, mercury, and copper. Zincken[3] in 1829 examined this palladium and he traced its source[4] to the mineral which he described as selenide of palladium under the name 'Selenpalladium'. Soon afterwards, however, he told Berzelius in conversation that on re-examination the mineral had proved to be native palladium.[5]

Zincken isolated the mineral by dissolving in acid specimens of dolomite containing clausthalite (PbSe) and dendritic flakes of gold. The silver-white metallic scales, found on the surface of the gold, were so minute that they floated on water and were scarcely visible to the unaided eye. Under the microscope they were seen to be six-sided plates, and, comparing them with iridosmine, he stated that there was a perfect platy cleavage perpendicular to the axis of the prism. Being brittle, he concluded that they could not consist of pure metal. When

[1] A small medallion (3 × 2·2 cm. ; 11·56 grams) of selenium, showing in relief a bust of Berzelius, came into the British Museum collection at about that time.

[2] O. Luedecke (Die Minerale des Harzes. Berlin, 1896, p. 6) also gives Zorge as a locality for allopalladium, but on what authority is not stated.

[3] C. Zincken, Ueber das Palladium im Herzogthum Anhalt-Bernburg. Ann. Phys. Chem. (Poggendorff), 1829, vol. 16, pp. 491–498. Abridged translation : C. Zinken, Sur le palladium trouvé dans le duché de Anhalt-Bernburg. Ann. Chim. Phys., 1830, ser. 2, vol. 44, pp. 206–213. The amount of palladium is not stated, but of several beads, one used for determining the specific gravity weighed 1·849 grams.

[4] A somewhat similar case is given by the presence of traces of palladium in the nickel-copper ores of Sudbury in Ontario ; this being the chief commercial source of the metal at the present day. But in this case the form in which the palladium occurs is not yet known.

[5] J. Berzelius, Jahres-Bericht über die Fortschritte der Physischen Wissenschaften (German translation by F. Wöhler), 1832, vol. 11, p. 202.

roasted in a glass tube a smell similar to that given by mercury lead selenide was noticed and a red ring of selenium was obtained. Chemical tests in the wet way showed the presence of palladium, lead, and silver in the material after roasting. No further description of the mineral was given. But later, in 1842, he gave a brief account of 'new selenium compounds'[1] from the Tilkerode ores. One of these, which he named 'eugenesite', was described as being silver-white, granular or scaly, and containing palladium, silver, gold, and selenium, the last possibly present as admixed lead selenide. No mention is made of the relation of this mineral to his previously described 'Selenpalladium'.

It is interesting to trace the vicissitudes of Zincken's mineral in the treatises on mineralogy,[2] which have copied one from another without adding any further information. At first under the name Selenpalladium (Selenpalladite of Dana, 1837) it was placed amongst the selenides and sulphides in the family of glances. Afterwards, when Zincken admitted that it was palladium rather than selenide of palladium, it was included under native palladium (regarded as cubic). Dana in the fifth edition of his 'System' (1868) again raised it to the rank of a species with the new name Allopalladium.

Zincken's description is very inadequate and unconvincing for establishing a mineral species, and although very nearly a century has elapsed there has been no confirmation of his results. The existence of a hexagonal modification of palladium has not even been suggested by the several examinations of the crystal-structure by X-ray methods. We must therefore conclude that 'allopalladium' 'Selenpalladium' is either (1) ordinary cubic palladium or (2) possibly potarite. If the former, the hexagonal outline of the scales presents no difficulty, for this is common enough in gold and other cubic metals. The 'cleavage' may have been imaginary, influenced by the comparison with iridosmine, and in any case it would be difficult to determine with certainty in such minute crystals. G. Rose[3] in his paper on the dimorphism of palladium (1842) added no new observations. In favour of (2) we have the association of mercury

[1] C. Zincken. Berg- und Hüttenm. Zeitung, 1842, vol. 1, col. 400. The name Eugenesite he had published the previous year in Ber. Naturwiss. Ver. des Harzes for 1840–41, col. 5.

[2] The large collection of treatises and text-books on descriptive mineralogy, almost complete in all editions, in the Library of the Mineral Department of the British Museum, is arranged chronologically, and so facilitates historical research.

[3] G. Rose, Ueber die Dimorphie des Palladiums. Ann. Phys. Chem. (Poggendorff), 1842, vol. 55, pp. 329–331.

minerals (tiemannite and onofrite); but, on the other hand, Zincken would surely have noticed a sublimate of mercury when he roasted the mineral in a glass tube. Without an opportunity of examining the original material, the evidence then appears to be in favour of regarding Zincken's mineral as ordinary cubic palladium.

Conclusions.—Potarite (J. B. Harrison, 1925) from the diamond-washings on the Potaro river in British Guiana is a definite compound of palladium and mercury in equal atomic proportions, PdHg, crystallizing as octahedra in the cubic system. Sp.gr. 15·0–16·1; hardness $3\frac{1}{2}$, brittle. Soluble in nitric acid to a brown solution.

'Allopalladium' from British Guiana (L. J. Spencer, 1924) is potarite. The original allopalladium or 'Selenpalladium' from the Harz (C. Zincken, 1829) is probably ordinary cubic palladium; the supposed hexagonal modification of palladium probably having no existence.

Addendum.—Smith Bracewell in his recent 'Report on the preliminary geological survey of the Potaro-Ireng district of British Guiana', Georgetown, Demerara, 1927, Combined Court no. 21, 60 pp., maps [Min. Abstr., vol. 3, p. 437] mentions this mineral under palladium (pp. 5 and 55) but without giving the name potarite. It has been found in small amounts over an extensive area in the Potaro district, and some further localities are noted. A conical fragment showing a radial aggregation of small crystals and weighing 2·61 grams, with specific gravity 15·00, has recently been found in the Kaieteur gorge.

A study of bauxite.

By T. V. M. Rao, Ph.D. (London), D.I.C.
Research student, Imperial College of Science and Technology, London.

[Communicated by Prof. W. W. Watts, F.R.S.; read November 1, 1927.]

Contents.

	PAGE
I. Introduction	407
II. Nomenclature	407
III. Lateritization	410
IV. Experiments on lateritization	411
V. Description of laterites from (*a*) India, (*b*) British Guiana, (*c*) Gold Coast, (*d*) Ireland, (*e*) France	416–21
VI. Relation of laterites to the original rock and to each other	421
VII. Mineral composition of laterites	422
VIII. Spherulitic structure in laterites	427
IX. Summary and conclusions	429
X. Acknowledgements	430

I. *Introduction.*

BAUXITE is of twofold interest due firstly to its economic importance, and secondly to the scope it affords for scientific investigation. When these two reasons are taken into consideration, one can easily account for the enormous and rapid accumulation of literature concerning this subject. Any attempt to give a detailed account of the literature will only mean unnecessary repetition of what has been already dealt with at great length by several writers, of whom Anderson [1] and Fox [2] may be specially mentioned. The relation between bauxite and laterite is so intimate that a detailed study of the one is impossible without any reference to the other, and as such the description of and frequent reference to the latter should not be considered as any digression from the subject.

II. *Nomenclature.*

Perusal of the literature on the subject makes one realize that the terms 'laterite' and 'bauxite' are used in a very loose sense. At one

[1] R. J. Anderson, Aluminium and its alloys. 1925.
[2] C. S. Fox, Bauxite. 1927. [Min. Abstr., vol. 3, p. 319.]

extreme iron [1] and manganese [2] ores are called laterites because they have been deposited as decomposition products of igneous rocks through a process somewhat similar to lateritization ; at the other extreme there are certain others [3] who consider free aluminium hydroxide as an essential constituent if the rock is to be called a laterite. There are still others [4] who make no distinction between laterite and bauxite and use the terms as synonymous. Under these circumstances it seems essential to state the sense in which the two terms are to be used.

The term laterite was originally applied by Buchanan [5] to the soft, decomposed gneisses found in southern India and used largely as a substitute for bricks. Since then it has been used for a variety of rock types, some of which do not possess even a remote resemblance to true laterites. No scientific definition of the term has ever been attempted, nor is there any general agreement as to its application.

Max Bauer [6] does not make any distinction between laterite and bauxite, nor does Holland [7] consider that the two terms mean different things. Between 1909 and 1911 correspondence on this point passed between Scrivenor,[8] Crook (loc. cit., and 1910, p. 234), and Evans.[9] Scrivenor laid stress on the suitability for building stones, Crook on the occurrence of free aluminium hydroxide, and Evans on the small amount of combined silica as the dominant feature of laterite. While Scrivenor's definition cannot be used for scientific purposes, that of Crook does not always make a distinction from clay. The most satisfactory definition is that of Evans, but it would have been much more precise if he had laid as much emphasis on the occurrence of free aluminium hydroxide as he does on the small amount of combined silica ; for there are specimens of altered igneous rocks with low percentage of silica, little or no alumina, and abundant iron oxides (cf. Simpson, loc. cit.). These are definitely not laterites, and if the low percentage of combined silica be the only criterion, iron ore, which they really are, would inevitably have to be included among them, and this would be undesirable.

[1] E. S. Simpson, Geol. Mag., 1912, dec. 5, vol. 9, p. 379.

[2] L. L. Fermor, Geol. Mag., 1911, dec. 5, vol. 8, p. 454.

[3] T. Crook, Geol. Mag., 1909, dec. 5, vol. 6, p. 524.

[4] F. W. Clarke, Data of geochemistry. 1920, p. 496.

[5] F. Buchanan, A journey from Madras through Mysore, Canara, and Malabar. London, 1807, vol. 2, pp. 436–437.

[6] Max Bauer, Neues Jahrb. Min., 1898, vol. 2, p. 163.

[7] Sir T. H. Holland, Rec. Geol. Survey India, 1905, vol. 32, p. 175.

[8] J. B. Scrivenor, Geol. Mag., 1909, dec. 5, vol. 6, pp. 431, 574 ; and 1910, dec. 5, vol. 7, pp. 139, 335, 382.

[9] J. W. Evans, Geol. Mag., 1910, dec. 5, vol. 7, p. 189.

It would obviate confusion if the use of the term laterite were restricted to the residual and occasionally redeposited type of rock with a comparatively small amount of combined silica and sufficient free aluminium hydroxide to form the dominant constituent, the remaining constituents being accessory. The laterite may be called quartzose or ferruginous according to the dominant accessory. All the constituents present in laterites have been found in the course of this work to show a marked tendency to form definite minerals.

Before proceeding farther the relation of bauxite to laterite has to be made clear. Clarke considers bauxite as no more than an aluminous variety of laterite, and in the nomenclature of Fermor (loc. cit., p. 514) it is only a type of laterite with sufficient free aluminium hydroxide to be of economic importance. Lacroix [1] defines it as 'une véritable roche' and classifies laterite as of bauxitic type if the aluminium hydroxide present in it is in a colloidal state, as distinct from the gibbsitic type in which the alumina is in a crystalline form. Any laterite containing more than 50 % of alumina, free or otherwise, would be bauxite according to Fox (loc. cit., p. 5). Evans is the only one to state unequivocally that laterite is a rock largely composed of the mineral bauxite with a chemical composition intermediate between that of gibbsite and diaspore, and the work carried out for this paper has gone far to confirm this view.

The next point in this section will be to state the distinction between bauxite and the other two known hydroxide minerals of aluminium. Berthier [2] was the first to identify bauxite as a distinct mineral having a composition corresponding to the formula $Al_2O_3 . 2H_2O$, and both Dana [3] and Miers [4] entertain the same view. Iddings,[5] however, differs from Berthier and does not include it among his rock-forming minerals. Holland (loc. cit., p. 176) attributes the composition of bauxite approaching a dihydrate to an intimate mixture of gibbsite and diaspore, thereby denying its occurrence as an independent mineral. Much emphasis should not be laid on the empirical calculation made by Warth [6] of the proportion of gibbsite and diaspore out of the total amount of alumina and water present in the specimens of laterites analysed by him

[1] A. Lacroix, Les latérites de la Guinée. Nouv. Arch. Mus. Paris, 1913, ser. 5, vol. 5, p. 255.

[2] P. Berthier, Annales des Mines, Paris, 1821, vol. 6, pp. 531-534.

[3] J. D. Dana, System of mineralogy, 5th edit., 1868, pp. 174 175.

[4] H. A. Miers, Mineralogy, 2nd edit., 1902.

[5] J. P. Iddings, Rock minerals, 2nd edit., 1911.

[6] H. Warth, Geol. Mag., 1903, dec. 4, vol. 10, pp. 154 and 172.

as they are not supported by microscopic evidence. It will be shown in the sequel that bauxite is an independent mineral forming the dominant constituent of laterites.

III. *Lateritization.*

Although the two end-products are known, the process of alteration of the original rock into laterites has so far been an open question. But several views suggesting the probable mode of formation have been expressed, and some of them may be briefly stated here.

As early as 1890 Walther [1] suggested that the frequently occurring thunderstorms of the tropics, together with the ozone present in the air, formed strong oxidizing agents, such as nitric acid. These agents in combination with the salts dissolved in rain-water were in his opinion sufficient to cause lateritization of rocks. Hayes [2] in 1894 suggested a different reason for the formation of the laterite deposits of the United States. Surface water with its dissolved oxygen while percolating through beds of shales reacted on the pyrites present in them, forming sulphuric acid, which in turn formed aluminium sulphate out of the aluminium silicate of the shales. The solution of the aluminium sulphate formed during its passage towards the surface came in contact with beds of limestone, forming unstable hydrated aluminium carbonate, which decomposed, giving off carbon dioxide and leaving behind hydrated aluminium oxide in the form of bauxite. In 1903 an ingenious suggestion was made by Holland [3] as the most probable cause of lateritization in India, and this view found favour among many other geologists. According to him some special form of bacteria removed the silica necessary for their development from the rocks, leaving behind aluminium hydroxide. Fermor [4] states that Holland later modified this view by including all vegetable organisms, of which bacteria, the lowest forms, were the most potent, being the most prolific, as the agents responsible for lateritization of rocks. Maclaren,[5] Cole,[6] and Campbell [7] are some of the many others to offer suggestions on this point. All these views only go to illustrate the difference of opinion among geologists regarding this form of alteration of rocks.

[1] J. W. Walther, Rec. Geol. Survey India, 1890, vol. 23, pp. 111-112.
[2] C. W. Hayes, Trans. Amer. Inst. Min. Eng., 1894, vol. 24, p. 253.
[3] Sir T. H. Holland, Geol. Mag., 1903, dec. 4, vol. 10, pp. 59–69.
[4] L. L. Fermor, Geol. Mag., 1915, dec. 6, vol. 2, p. 127.
[5] J. M. Maclaren, Geol. Mag., 1906, dec. 5, vol. 3, p. 539.
[6] G. A. J. Cole, Trans. Roy. Dublin Soc., 1896, ser. 2, vol. 6, p. 105.
[7] J. M. Campbell, Trans. Inst. Min. Met., 1910, vol. 19, pp. 432–457.

IV. *Experiments on Lateritization.*

With a view to studying the exact process of formation of laterites in nature the following experiments were carried out. Figs. 1 and 2 show the chief piece of apparatus set up for this purpose. The circular copper cylinder *B* with its lid formed a jacket round four hard-glass tubes each about a foot long and half an inch in diameter. These tubes were filled nearly to the top with granulated fragments of the rock intended for treatment. The granules were just large enough to pass through a sieve of ten meshes to the inch. The stone jar *C* contained a 3 % solution of sulphuric acid, which was allowed to drop, by means of a syphon tube, on the granulated rock in one of the hard-glass tubes at the rate of three drops a minute. A 5 % solution of carbonates of potassium and sodium, in the proportion of one part of potassium carbonate to four parts of sodium carbonate, contained in the stone jar *D* was allowed to drop on the contents of the second hard-glass tube at the same rate. Three to four drops from the jar *E*, which contained only distilled water, were allowed to trickle through the granules of the rock held in the remaining two glass tubes. Besides the distilled water, from four to eight bubbles per minute of carbon dioxide from the cylinder *F* were led into one of the last two glass tubes. Thus solutions of (i) sulphuric acid, (ii) alkali carbonates, (iii) carbonic acid, and (iv) distilled water alone, were allowed to percolate through the granules of the rock packed in the four glass tubes. After percolating, these reagents dropped through the narrow drawn lower ends of the hard-glass tubes into small funnels supported below the copper cylinder and were led by means of rubber tubings to the sink. An unfailing supply of the above reagents was maintained throughout the period of the experiment.

Water from the tap, after flowing through a long coil of composition tubing (lead alloy), entered the copper cylinder *B* through a side tube near its lower end, flowed out into the sink through an opening on the side near its top, and in this manner a constant current of water was allowed to circulate in the cylinder. The coil of composition tubing, about 12 feet long, was kept immersed in a bath of water *A*, whose temperature was so adjusted by means of a thermostat as to maintain the water circulating in the cylinder *B* within a constant range. The bath *A*, the cylinder *B*, and the exposed ends of the composition tubing were all wrapped in folds of asbestos cloth to prevent radiation of heat.

The specimen of rock used for the treatment described above was a portion of the fresh basalt of the Upper Volcanic Series from the Giant's

Causeway. The experiment was run continuously for a period of nine months, and the temperature of the water in the copper cylinder was maintained throughout the period between 32° and 52° C., that is, slightly above tropical temperature. But at the end of six months the supply of sulphuric acid was cut out and alkali carbonate solution introduced instead into the first hard-glass tube. Before this operation a

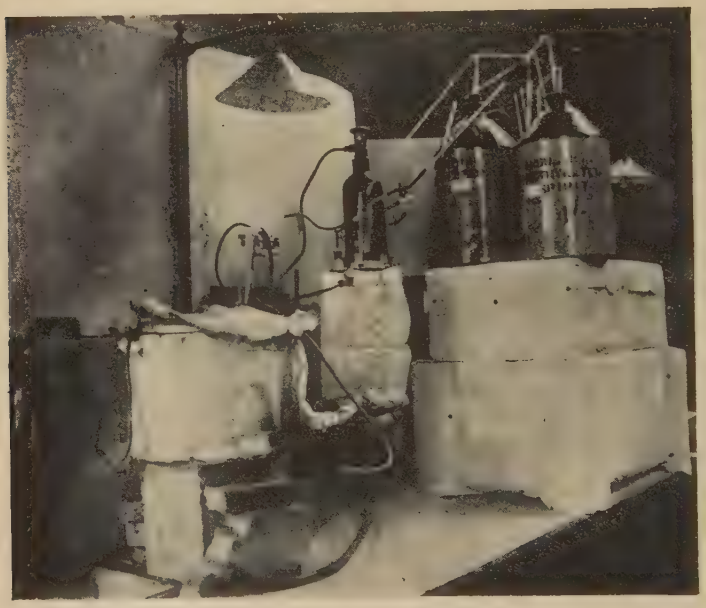

Fig. 1. Photograph of apparatus.

portion of the rock from this glass tube was removed for the purpose of studying the action of the acid.

Throughout the experiment, iron in a ferric state was proved to be removed in varying amounts from all the tubes. One or more of the other constituents of the rock were also leached out in varying amounts from some of the tubes, but it was not possible to examine them in detail.

Another part of the experimental work consisted in studying the action of organic acids on rocks. A humic acid solution extracted from peat was allowed to flow through a glass tube filled with the same specimen of granulated basalt as before. For a short time the temperature of the

glass tube with its contents was maintained between 30° and 50° C. This part of the work was also carried out for nine months. The jelly-like humic acid had to be deflocculated with a few drops of ammonia before it could be made fit for use.

A study of the effect of pressure on rocks formed the third part of the experimental work; but in this case a specimen of dolerite was used. Broken bits of this rock were packed inside a small copper wire gauze bag

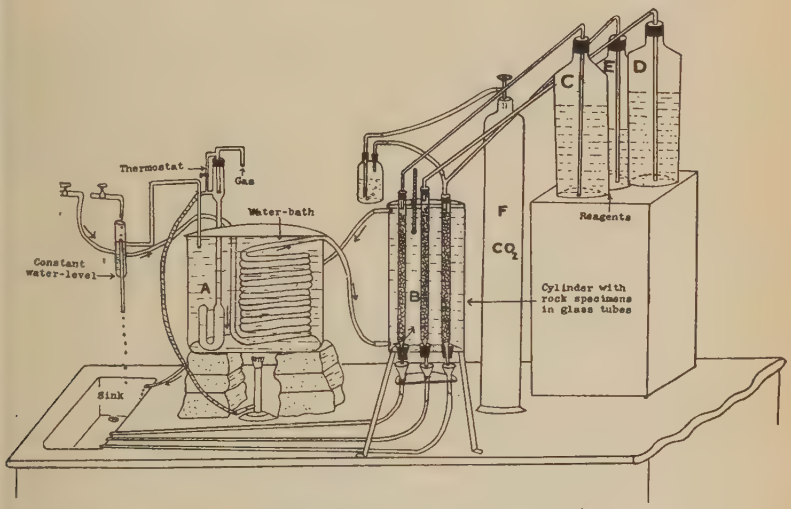

Fig. 2. Diagrammatic sketch of apparatus.

suspended in an autoclave, and were subjected to steam pressure varying from 800 to 1,600 lb. to the square inch at a temperature ranging from 250° to 330° C. The treatment extended over a period of six months at the rate of six hours per day. A small amount of carbon dioxide was also introduced into the autoclave every morning before it was started.

Description of resulting specimens.—After the various treatments the specimens were removed from the several glass tubes, washed till they were free from the reagents and dried at 110° C. for four hours, and were then used for chemical analysis and microscopic examination. The chemical composition of the original and resulting specimens is given in the following table, which was obtained by taking the mean in each case of two independent analyses with concordant results.

Chemical composition of the rock before and after the various treatments.

[Analyses by T. V. M. Rao.]

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2	51·20	71·32	63·42	48·84	50·30	50·63	50·98	44·19	41·55
Al_2O_3	14·60	3·96	3·40	18·25	17·93	15·68	15·34	13·56	15·26
Fe_2O_3	4·56	4·79	9·18	10·61	11·85	11·01	12·06	11·30	15·29
FeO	8·13	0·26	0·85	0·76	0·75	0·79	0·79	0·94	0·68
MgO	4·40	0·22	6·20	5·42	2·21	4·76	4·75	16·56	11·47
CaO	10·35	8·06	11·48	9·32	9·85	9·66	9·44	8·46	8·70
Na_2O	3·23	1·09	2·01	2·48	2·03	2·60	3·06	2·06	1·35
K_2O	0·82	0·85	1·76	1·19	0·93	0·74	0·42	0·36	0·17
H_2O+	2·11	9·42	1·01	2·07	2·51	2·39	2·40	1·68	3·20
TiO_2	0·96	0·42	0·81	1·16	1·50	1·17	0·94	0·83	1·49
CO_2	0·04	0·01	0·03	0·24	0·16	0·08	nil	0·29	0·40
Total	100·40	100·40	100·15	100·34	100·02	99·51	100·18	100·23	99·56

I. Fresh basalt from Giant's Causeway, Co. Antrim.—The basalt used for the experimental work is black in colour and very fine-grained. In thin sections labradorite felspar and augite are found to be present both in the groundmass and as porphyritic crystals. Some interstitial glassy material and accessory crystals of ilmenite and magnetite make up the rest of the rock. No trace of alteration can be detected either in hand-specimens or in thin sections of the rock.

II. Basalt after six months' treatment with sulphuric acid.—The granules are grey in colour and are very light. The chemical analysis proves a tremendous increase in the amount of silica and water and a slight increase of ferric iron. The other constituents, especially alumina and ferrous iron, have diminished. Examination of crushed grains shows abundant quartz, augite in different stages of alteration and often presenting a spongy appearance, and a complete absence of felspar. Augite partly altered to quartz is occasionally seen, but the latter is too abundant to be derived entirely from this source and should have been derived from felspar[1] also.

III. No. II after further treatment for three months with alkali carbonates.—The specimen was reduced to a grey powder. An appreciable amount of silica has been removed by the action of the alkali carbonates.

IV. Basalt after nine months' treatment with alkali carbonates.—The chemical analysis proves an increase in the amount of alumina and a decrease in that of silica. On examination of the crushed grains it is found that some of the felspar crystals have partly or completely altered to an opaque mass very much resembling the milky-white grains of bauxite to be described in the next section (cf. Leonard, loc. cit., p. 32).

V. Basalt after nine months' treatment with water and carbon dioxide.—The action of carbon dioxide seems to be similar to that of alkali carbonates, though the difference is not so appreciable.

[1] Cf. R. J. Leonard, Econ. Geol., 1927, vol. 22, p. 25.

VI. Basalt after nine months' treatment with distilled water.—The only difference is in the silica content, showing that water by itself is capable of removing silica in small amounts.

VII. Basalt after nine months' treatment with humic acid.—Humic acid seems to have had no action.

VIII. Dolerite (locality unknown).—The specimen used for treatment under pressure is an olivine-dolerite having a groundmass largely made up of fresh crystals of felspar and augite. Porphyritic crystals of olivine, partly altered to serpentine, are abundant. The vesicles present in the rock are filled with calcite; ilmenite and magnetite occur as accessories.

IX. Dolerite after six months' treatment with steam and carbon dioxide under pressure.—The difference after this treatment is only in silica and magnesia, the former due to the effect of steam and the latter probably to carbon dioxide. The crushed grains of the specimen are largely composed of felspar and augite, both of which are fresh; but there is no trace of serpentine, which should have been decomposed by steam and carbon dioxide.

Review of experimental work.—From the foregoing description of the resulting specimens it will be noticed that the action of acid results only in an increase of silica. Water by itself has little action in the process of lateritization, and that of humic acid is not worth mentioning. The effect of steam and pressure is analogous to that of water except that it is more intense. It is only alkali carbonates, and to a small extent carbon dioxide, that effect a reduction of silica and an increase of alumina. No doubt a certain amount of alumina is also removed, but that is negligible when compared to the amount of silica leached out.

From the results of the experimental work it is safe to conclude that the whole key to the process of lateritization rests with the alkali carbonates. Further, the fact that the alkali radicals present in igneous rocks and shales do not by themselves bring about this form of alteration is sufficient proof for considering that they should be present as carbonates. Hence the role played by carbon dioxide during lateritization is significant.

The process of lateritization may now be summarized as follows. The carbon dioxide present in rain-water combines with the alkalis present in rocks and soils forming alkali carbonates. Aqueous solutions of these carbonates react on the felspars and other aluminium silicate minerals present in rocks, giving rise to alkali silicates and hydrated aluminium carbonates; the former are removed in solution and the latter, being unstable, are decomposed into carbon dioxide and hydrated aluminium oxide, which is deposited in the form of bauxite. Those constituents of the original rock that are not or only partly decomposed are left behind as accessories, and these with the bauxite form deposits of primary

laterite. The chemical reaction involved in the alteration to laterite may be expressed as follows:

Aluminium silicates + alkali carbonates + water → alkali silicates + hydrated aluminium carbonate.

Hydrated aluminium carbonate → hydrated aluminium oxide (bauxite) + carbon dioxide.

Some of the liberated carbon dioxide may help in the removal of magnesia as bicarbonate. The fact that lateritization takes place only in tropical countries, although the necessary constituents are always everywhere present, suggests the need for tropical temperature for this type of alteration.

Geological significance.—The results of the experimental work are all the more convincing as they bear certain points of resemblance to evidence obtained in the field. Kitson [1] refers to the presence of carbon dioxide in the shafts and borings put down in the laterite deposits of the Gold Coast, and this should be due to the breaking down of the hydrated aluminium carbonate as deduced from the experimental work. Hayes suggests the formation of hydrated aluminium carbonate as an intermediate product during the formation of the American laterite deposits. Again, the occurrence in nature of the mineral dawsonite suggests the formation of hydrated aluminium carbonate as quite feasible.

In conclusion it may be observed that when it is possible for lateritization to take place by the action of the constituents mostly present in the rock itself, there seems no necessity to invoke the aid of extraneous agents such as vegetable organisms.

V. *Description of Laterites.*

(*a*) *India.*—The chief deposits of laterites in India are derived from the Deccan traps, although those formed from metamorphic and sedimentary rocks are not uncommon. In hand-specimens these laterites are massive, spherulitic, vermicular, or conglomeratic, the last type being not so common as the others. The massive type resembles a piece of burnt clay except as regards its colour. The spherulitic type may be full of spherules of varying size, the matrix forming merely a cement, or there may only be a few. In some cases the spherules are easily detachable intact. When split open these spherules are found to have either a concentrically banded structure or to be hollow and partly filled with a white powder. The structure, composition, and relation of these spherules

[1] Sir A. E. Kitson, Outlines of the mineral and water resources of the Gold Coast, 1924, p. 22.

to the matrix will be fully discussed at the end of this paper. The matrix, whether forming merely a cementing material or the bulk of the specimen, may be either more or less stained with iron than the spherules, and is specifically lighter than them. The pores in the vermicular type lead to zigzag holes which may be empty or lined or filled with haematite, limonite, or some indistinguishable powder having a red, yellow, or brown colour. One or all of the structures described above may be found in the same deposit and even in the same specimen.

The colour varies through a wide range, but is usually in some shade of pink, red, or brown. It may or may not be evenly distributed, and when uneven the intensity may vary in different patches. The colour with its different shades is entirely due to oxides and hydroxides of iron. Those poor in iron are grey in colour. But in all of them intensity of colour is not always a true indication of the amount of iron content.

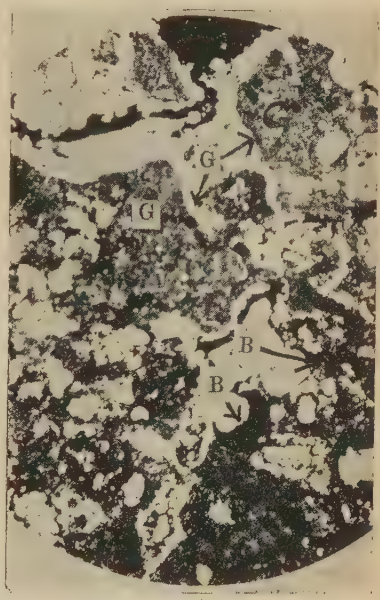

FIG. 3. Photomicrograph showing bauxite (B) altering into gibbsite (G). Central Provinces, India. ×35.

The thin sections of the rock are opaque, as they always are, and afford little scope for detailed examination, especially with polarized light, any possible microscopic work being carried out by using reflected light. Even the few identifiable minerals present are often masked by the iron stain, which, due to its unevenness, imparts a chequered appearance to the whole section. In many cases the sections are full of holes and zigzag cracks, often filled or lined with crystals of gibbsite (fig. 3). The peculiar arrangement of these crystals in the holes and cracks leaves little doubt regarding their secondary formation after the lateritization of the rock. The structures, especially the spherulitic and the conglomeratic, of the specimens are better displayed in thin sections than in the large masses. Some of the spherules have a core of an oxide or hydroxide of iron, very often of limonite. Occasional groups of weathered and iron-stained

crystals of felspars, probably plagioclase, platy grains of ilmenite, and four-sided grains of magnetite are the only identifiable minerals in thin sections. But an examination of the crushed grains of the rock reveals the presence of muscovite, weathered biotite, zircon, amphibole, pyrites, tourmaline, sphene, and rutile. The composition and properties of the opaque grains having a milky-white appearance when not stained with iron and forming the bulk of the crushed rock will be discussed in full in a subsequent section.

(*b*) *British Guiana.*—According to Harrison [1] these laterites are formed mostly from gabbros and diabases and to a small extent from porphyries, granites, and gneisses. Most of the specimens examined are massive and the others are nodular, stalactitic, or granular, the granules being loosely held together. They are mostly cream coloured, a few having a mottled appearance. In the stalactitic and nodular types iron in the form of haematite or limonite segregates in the centre forming a core. Thin sections reveal no new information beyond the fact that they are devoid of holes and cracks.

(*c*) *Gold Coast.*—There are several deposits with varying grades of ore, but the important ones are at Sefwi Bekwai and at Mt. Ejuanema. The specimens are mostly massive, rubbly, or granular, though spherulitic forms are not uncommon. Occasionally vermicular structure with the vermicules filled with a brown powder is also met with. Some of the specimens from Sefwi Bekwai are full of minute holes and white specks, of which the latter on microscopic examination are found to be made up of bunches of crystals of gibbsite. The spherules, which show concentric banding, are neither as numerous nor as easily detachable intact as in the Indian specimens.

The colour, which in the majority of cases is uniformly distributed, varies from orange, yellow, or brown to bright red. The iron stain, to which the colour is due, is, in the opinion of Kitson (loc. cit., p. 21), imparted subsequently to the lateritization of the rocks. If so, the fact that it has not stained the crystals of gibbsite is a further proof of their secondary nature formed after the lateritization of the rock. In hand-specimens, and in thin sections as well, it is possible to observe bedding-planes and parallel arrangement of lenticles reminiscent of the parent-rock.

The remarks made regarding the examination of thin sections of Indian laterites apply equally well to these specimens also. Among the crushed grains are found ilmenite, fresh or partly altered to leucoxene, brown

[1] Sir J. B. Harrison, Geology of the goldfields of British Guiana, 1908.

tourmaline, secondary sphene, occasional grains of amphibole, kyanite, and magnetite, the last mineral often altered to limonite.

(*d*) *Ireland.*—The writer had an opportunity for studying in the field the laterite deposits of Antrim during a visit paid there in 1925. These deposits, formed by the weathering of the basalts of the Lower Volcanic Series, are not as extensive as in India nor are they of any great economic importance. The basalts of the Upper Volcanic Series form a thick mantle over most of the deposits and there are only very few good exposures. The exposure along the cliff at the Giant's Causeway is probably the best and affords good facilities for a study of the process of lateritization. Along the path excavated on the cliff it is possible to trace the gradual passage of the fresh basalt at the western end into the soft red-coloured band of laterite at the eastern end. A close examination of this band leads one to conclude that the agent responsible for the alteration should have worked its way along the joints and crevices of the basalt and brought about the alteration.

The laterites in the south of Antrim are the results of alteration of acid igneous rocks such as rhyolites. Naturally these laterites are not so ferruginous as those derived from basalts and they were at one time exploited. In hand-specimens these laterites are massive or conglomeratic, the ferruginous varieties being bright red in colour. They are very friable and can be crushed between the fingers. In thin sections they are entirely opaque and quite compact. Secondary quartz is the only recognizable mineral. Besides the ubiquitous opaque milky-white grains, there are present in the crushed rock grains of anatase light blue and light green in colour, simple and geniculate twins of rutile, octahedral crystals of magnetite, bleached biotite, tourmaline, and zircon; occasionally transparent greenish-yellow crystals of rutile are also met with. Rutile and anatase are secondary as they are both absent in the original rock. But only a part of the magnetite is secondary and derived from the ilmenite of the basalt.

(*e*) *France.*—Specimens of laterites from France, the classical area for these rocks, were also examined with a view to making the study as comprehensive as possible. These laterites overlie rocks of Upper Cretaceous age forming a discontinuous stretch in the south and south-east of France. The specimens examined are either massive or spherulitic. Blocks of the massive type are quite white outside, resembling a piece of chalk with no trace of iron; but in the interior the material is red in colour, the iron having segregated towards the centre. The spherulitic variety is dark red in colour, the matrix being more intensely stained than the spherules.

The spherules show concentric banding and are closely cemented by the matrix.

The results of the chemical analyses of some of the typical specimens from the countries described above are given in the following table.

Analyses (by T. V. M. Rao) of Laterite.

No.[1]	5.	12.	15.	54.	7A.	7.	17.
SiO_2 ...	1·52	1·90	2·04	25·26	1·13	44·54	1·18
Al_2O_3 ...	55·56	58·83	55·20	14·49	60·62	34·78	58·47
Fe_2O_3 ...	4·18	2·89	3·97	34·85	2·26	1·22	6·27
MnO ...	n.d.	n.d.	n.d.	9·02	n.d.	n.d.	n.d.
MgO ...	0·11	0·11	0·11	0·18	0·21	nil	0·09
CaO ...	0·41	0·74	0·71	0·30	0·66	0·44	0·40
Na_2O ...	0·30	2·75	0·72	0·17	0·27	0·27	0·34
K_2O ...	0·44	0·70	0·46	0·21	0·37	0·35	0·08
H_2O+ ...	28·85	27·06	24·65	14·22	32·73	17·92	32·26
TiO_2 ...	8·76	5·33	11·69	1·13	1·58	0·26	1·27
Total ...	100·13	100·31	99·55	99·83	99·83	99·78	100·36

No. 5.—West scarp, Samnapur, Central Provinces, India.
12.—Ridge of Nauga, Belgaum, Bombay, India. (806.)
15.—NW. of Samnapur, Central Provinces, India. (1128.)
54.—Varkala, Travancore, India.
7A.—Demerara, British Guiana.
7.—British Guiana (unlocalized).
17.—Bepo Khini, Sefwi Bekwai, Gold Coast. (9434.)

No.[1]	22B.	29.	32.	37.	33.	60.	61.
SiO_2 ...	0·61	0·61	0·69	21·29	7·03	3·09	1·90
Al_2O_3 ...	64·99	59·69	56·31	46·64	49·37	67·10	76.05
Fe_2O_3 ...	2·89	10·61	10·72	2·58	5·78	7·79	1·87
MnO ...	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	0·03
MgO ...	0·14	0·33	0·33	0·09	0·20	0·14	0·15
CaO ...	0·63	0·44	0·46	0·71	1·07	1·27	0·56
Na_2O ...	0·84	n.d.	n.d.	0·26	trace	0·45	0·38
K_2O ...	0·06	n.d.	n.d.	0·26	trace	0·14	0·33
H_2O+ ...	27·87	23·97	29·78	+23·80	30·43	17·73	15·30
				−2·12			
TiO_2 ...	2·40	4·05	0·85	4·08	6·22	2·52	3·34
Total ...	100·43	99·70	99·14	99·71	100·10	100·23	99·91

No. 22B.—Ejuanema, Gold Coast, West Africa. (2.)
29.—Top of Mt. Ejuanema, Gold Coast. (14911.)
32.—Top of Mt. Ejuanema, Gold Coast. (14911.)
37.—Ballintoy, Co. Antrim, Ireland.
33.—Straid, Ballynure, Co. Antrim.
60.—Le Valare, Foix, Ariège, France.
61.—Brignoles, Var, France.

[1] These numbers are those of specimens in the writer's collection. The numbers given after some of the localities are those of the Indian and Gold Coast Surveys.

With the high alumina content in most of them they should prove to be of economic importance. The high percentage of titanium content is a noteworthy feature of Indian specimens. Evidence of the occurrence of carbon was obtained in the course of the analysis in some of the Irish specimens, and this might account for the abnormally high percentage of hygroscopic moisture in some of them. Reference will be made presently regarding the low percentage of water in the two French specimens analysed.

VI. *Relation of Laterites to the original rock and to each other.*

Comparison of the composition of laterites (II) and of the rocks (I) from which they were derived.

INDIA.[1]

	Set No. 1.			Set No. 2.			Set No. 3.		
	I.	II. (No. 5).	(I−II)/I	I.	II. (No. 12).	(I−II)/I	I.	II. (No. 15).	(I−II)/I
SiO_2	48·84	1·52	− 0·96	48·62	1·90	− 0·95	49·98	2·04	− 0·95
Al_2O_3	14·37	55·65	+ 2·82	14·12	58·83	+ 3·40	12·51	55·20	+ 3·45
Fe_2O_3	13·70	4·18	− 0·69	15·06	2·89	− 0·64	15·94	3·97	− 0·75
MgO	5·33	0·11	− 0·98	5·29	0·11	− 0·97	5·42	0·11	− 0·97
CaO	9·82	0·41	− 0·96	9·49	0·74	− 0·92	10·00	0·71	− 0·92
Na_2O	2·26	0·30	− 0·88	2·95	2·75	− 0·71	2·65	0·72	− 0·72
K_2O	0·52	0·44	− 0·15	0·60	0·70	+ 0·16	0·30	0·46	+ 0·53
H_2O+	2·50	28·85	+ 10·74	2·28	27·06	+ 10·86	0·95	24·65	+ 24·94
TiO_2	2·63	8·76	+ 2·33	0·88	5·33	+ 2·28	2·27	11·69	+ 4·14

BRITISH GUIANA.[2]

	Set No. 4.			Set No. 5.			Set No. 6.		
	I.	II.	(I−II)/I	I.	II.	(I−II)/I	I.	II.	(I−II)/I
SiO_2	52·00	3·33	− 0·93	49·06	3·13	− 0·93	51·09	2·71	− 0·94
Al_2O_3	17·29	46·80	+ 1·70	18·86	56·42	+ 1·99	15·70	64·86	+ 3·76
Fe_2O_3	12·08	26·40	+ 1·18	6·91	11·59	+ 0·67	11·20	0·85	− 0·93
MgO	6·95	nil	− 1·00	10·95	0·20	− 0·98	7·74	0·36	− 0·93
CaO	8·80	nil	− 1·00	11·70	0·13	− 0·98	9·11	0·33	− 0·99
Na_2O	2·81	nil	− 1·00	0·97	0·13	− 0·86	2·38	nil	− 1·00
K_2O	0·18	nil	− 1·00	0·06	0·10	− 0·66	1·55	0·15	− 0·90
H_2O+	0·35	22·96	+ 64·02	0·43	27·84	+ 63·74	0·35	30·47	+ 86·05
TiO_2	0·53	0·69	+ 0·30	0·88	0·83	− 0·05	1·70	0·75	− 0·50

[1] For these analyses of Indian basalts occurring in the same localities as the laterites, vide H. S. Washington, The Deccan traps and other plateau basalts. Bull. Geol. Soc. Amer., 1922, vol. 33, p. 765. The ferrous iron in these analyses has been converted into ferric iron.

[2] For these analyses of both the original rocks and the laterites, vide Sir J. B. Harrison, Rep. and Corres. relating to the bauxite of British Guiana, 1919. Colonial Office Publication. In set no. 4 the original rock is basalt, in no. 5 epidiorite, and in no. 6 diabase.

It is shown above that it is possible to trace a relationship between some of the constituents of the original rock and those of the laterites derived from it. In each of the above sets of tabular statements the first vertical column gives the chemical composition of the original rock occurring in the same locality as the corresponding laterite, the second that of the laterite itself, and the third the proportion of gain or loss of each of the constituents.

It will be noticed that the proportion lost of silica and oxides of calcium and magnesium is identical, or in other words the proportion of these constituents present in residual laterites is invariably constant. If so, when these proportions are reached, these constituents should become invulnerable to the further action of the lateritizing agents. It is then possible to surmise that the process of lateritization, which in the main consists of the leaching out of silica, magnesia, and calcium oxide from rocks is limited in its scope. It may also be possible to trace this relationship between the original and altered rocks of other countries—of course only if the laterites are primary.

In a pamphlet on lateritization Chautard and Lemoine[1] have indicated a method of calculating the amount of silica, alumina, and other constituents involved during this type of alteration on the assumption that all the titanium present in the original rock is left unaffected in the altered product. But chemical and microscopic examination of low-level laterites and calculation based on the amount of titanium oxide present in the original rock have proved that an appreciable amount of titanium is invariably removed, and as such much stress should not be laid on the methods suggested by these workers.

It was not found possible to represent the constituents of laterites in the form of a variation diagram.

VII. *Mineral Composition of Laterites.*

Attention may now be directed to the consideration of the several minerals occurring in laterites and their correlation with the chemical composition.

Alumina.—Hydrated oxide of aluminium is the dominant constituent of laterites, and the consideration of its nature and mode of occurrence is the prime object of this paper. Aluminium hydroxide has so far been known to occur in the form of three compounds, two of which, viz. gibbsite and diaspore, are easily determined by their definite physical, chemical, and

[1] J. Chautard and P. Lemoine, La latérisation. Bull. Soc. Industrie Minérale, Saint-Étienne, 1908, ser. 4, vol. 9, reprint 37 pp.

mineralogical properties. But there is a great divergence of opinion regarding the consideration of bauxite as a definite mineral. Gibbsite occurs as a secondary mineral and forms only a very small proportion of laterites. Diaspore has never been known to occur in laterites but is found associated with minerals of thermodynamic origin, signifying that mere conditions of lateritization are not conducive to its formation; consequently it cannot be expected to occur as a normal constituent of laterites.

Bauxite.—During the description of specimens of laterites it was repeatedly pointed out that the thin sections and the crushed grains of the rock contained an opaque material having a milky-white appearance when not stained by iron. Microscopic examination did not reveal any further information regarding its optical and mineralogical properties.

The specifically light residue obtained from a bromoform separation of the crushed grains of the rock proved on microscopic examination to consist mostly of these milky-white grains. Further, it also formed the bulkier part of the bromoform separation and had the following chemical composition. The light residue of laterite no. 9 from Netarhat, Bihar and Orissa, India (134), gave the following results on analysis:

SiO_2.	Al_2O_3.	Fe_2O_3.	MgO.	CaO.	Alkalis.	H_2O+.	TiO_2.	Total.
0·40	62·96	3·94	0·38	0·35	n.d.	25·04	5·25	98·32

Recalculation of the above analysis after excluding the minor constituents shows that there is 71·74 % of alumina and 28·26 % of water, and this proportion is not near to a mono- or trihydrate of alumina. Evidently the aluminium hydroxide forming the dominant constituent of laterite is neither diaspore nor gibbsite and must be nothing other than bauxite.

Composition of bauxite.—With a view to determine the composition of bauxite Arsandaux[1] carried out some interesting work with certain highly aluminous rocks occurring in France. By digesting several specimens of these rocks with concentrated hydrochloric acid on a water-bath for about an hour, he seems to have succeeded in removing all the iron and obtaining residues consisting mostly of alumina, some titanium oxide, and a trace of silica. On chemical analysis these residues were found to contain alumina and water in a proportion sufficient to form only a monohydrate. In about thirty cases treated in this fashion he found only one instance of variation and all the rest agreed. The comparatively small amount of water present in the French specimens described

[1] H. Arsandaux, Compt. Rend. Acad. Sci. Paris, 1909, vol. 148, pp. 936, 1115.

in the present paper also goes to support Arsandaux's conclusions. But the proportion of alumina and water present in specimens from other countries are not in favour of his views. The following table gives the results of chemical analyses of two typical specimens of laterites, one from India and the other from the Gold Coast, after they were treated with hydrochloric acid. Since an hour's treatment had not removed much of the iron, they were digested on the water-bath till the acid began to attack the bauxite of the rock.

	India (no. 12).		Gold Coast (no. 32).	
SiO_2 ...	0·77	... ...	1·17	
Al_2O_3 ...	65·63	(70·9)[1]	63·62	(71·7)[1]
Fe_2O_3 ...	2·51	... ...	2·12	
H_2O+ ...	25·64	(29·1)	27·09	(28·3)
TiO_2 ...	3·13	... ...	4·15	
	97·68	100·00	98·15	100·00

Comparison of these two partial analyses with those of the original specimens (vide p. 420) shows the rather surprising result that very little of the alumina has been attacked by the acid, though the treatment was quite a severe one; nor is there much change in the amount of water. The proportion of alumina and water in both cases is nearer to that of a dihydrate than to the other two known aluminium hydroxides. The percentages of alumina and water in all the laterites, whose chemical composition is given on p. 420, also on recalculation after excluding the accessories correspond to a dihydrate and never to a monohydrate. Obviously the specimens described by Arsandaux and the two French ones described in this paper do not contain any bauxite, but probably some other hydroxide of alumina corresponding in composition to a monohydrate. For reasons already given this monohydrate cannot possibly be diaspore. Thus there arises the probability of the occurrence in nature of aluminium hydroxide minerals other than the three now known, and the fact that there are laterites (C. S. Fox, loc. cit.) containing still less water than a monohydrate lends further support to this view.

Doubt may arise as to whether the mono- or the dihydrate, both being found in France, should be called bauxite. The following analysis made by Berthier in 1821 will help to clear that doubt.

SiO_2.	Al_2O_3.	Fe_2O_3.	H_2O.	Total.
—	52·0	27·6	20·4	100·0

[1] Numbers in brackets indicate percentages of alumina and water exclusive of the minor constituents.

After excluding the iron there is in the above analysis 71·8% of alumina and 28·2% of water, and this approximates to the dihydrate in composition. Evidently Berthier gave the name bauxite to the dihydrate. Whether analysed in the manner suggested by Arsandaux or otherwise, the proportion of alumina and water in the specimens whose composition is given on p. 420 (France excluded) also corresponds to a dihydrate. Thus as there is a definite dihydrate occurring in nature, there is no justification in giving the name bauxite to any other aluminium hydroxide. These French specimens corresponding in composition to a monohydrate may provisionally be considered as an amorphous variety of diaspore.[1] Further, Berthier has a claim for priority and hence it does not seem proper that a name given by him for a particular mineral should be given to any other.

The definite chemical composition of bauxite, as seen from the examples given above, also settles the question of its being a distinct mineral. As a further proof, an experiment was carried out to see if bauxite would behave in a manner similar to other minerals. It has already been pointed out by previous workers (Fox and Arsandaux) that laterite on heating gave off water at uneven rates; but the significance of this feature had not been fully realized. Samples of laterite, gibbsite, and limonite were separately heated in an electric furnace to different temperatures, and curves were plotted showing their different rates of dehydration. As can be seen from fig. 4, none of the specimens gave off its combined water at a uniform rate.

It is too much to expect that the uneven nature of the curve for laterite,[2] which is so pronounced, is due to the small amounts of gibbsite and limonite that may be present in it. So it would not be unsafe to consider that bauxite, which forms the dominant constituent of laterite, should also have contributed to its unevenness. This uneven rate of dehydration would serve as a further proof of bauxite being a definite mineral and not a colloid (cf. Lacroix, loc. cit.).

It is also clear by now that bauxite is not a mixture of gibbsite and diaspore, since the former is of subsequent formation to bauxite and the latter never occurs in laterites.

Silica.—Occurrences of silicate minerals and quartz in laterites have already been recorded. Rational analysis[3] revealed the fact that silica

[1] A crystalline aluminium monohydrate in French bauxite has recently been named 'boemite' by J. de Lapparent, Compt. Rend. Acad. Sci. Paris, 1927, vol. 184, p. 1661 [Min. Abstr., vol. 3, pp. 369, 430].

[2] This differential method has to be adopted as it is never possible to obtain bauxite free from gibbsite, limonite, or both.

[3] For a detailed account of the estimation of the different forms in which

was present in laterites in colloidal form also. Felspar, kyanite, muscovite, biotite, zircon, sphene, tourmaline, and amphibole are the important silicate minerals present. The quartz present may be primary if derived from the original rock or it may be secondary. The silica that is not

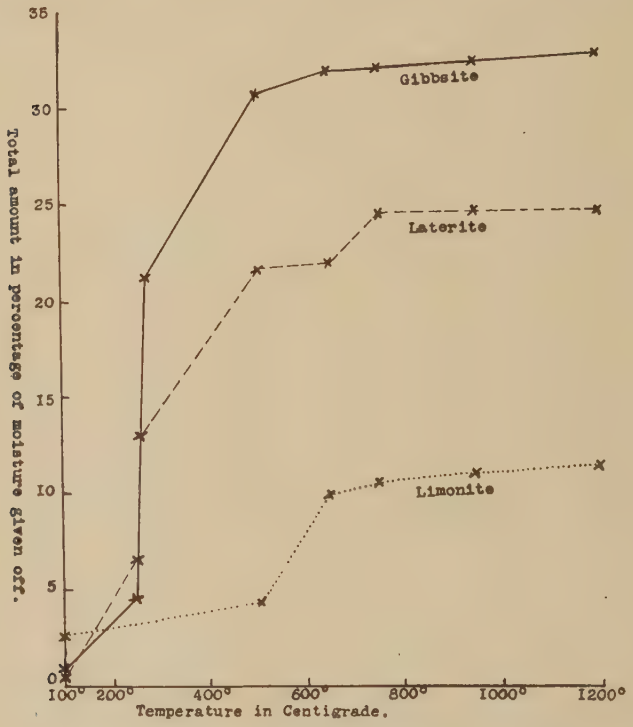

Fig. 4. Curves showing the different rates of dehydration of laterite, gibbsite, and limonite.

included in any of the above forms is present as a colloid—the form in which it should have separated out of the rock before it formed secondary minerals.

Iron.—Of the various oxides and hydroxides of iron, haematite, magnetite, and limonite are the only ones to be definitely identified. Grains of pyrite are also of occasional occurrence. Of these iron-bearing minerals only the pyrite and a portion of the magnetite are primary.

Titanium.—The form in which this constituent occurs in laterites has

silica occurs in laterites, vide J. W. Mellor, Treatise on quantitative inorganic analysis, 1913, pp. 658 and 668.

so far been a matter of speculation. Maclaren is probably the first to point out the occurrence of ilmenite and doubtfully of rutile in laterites. Lacroix is of opinion that it is in the form of ortho- and metatitanic acid. Wysor[1] seems to have identified pseudobrookite besides ilmenite in the specimens examined by him. Fermor[2] denies the occurrence of any titanium-bearing minerals in the laterites of India. Fox thinks that it is in the form of a gel. Although an attempt made to estimate accurately whether all the titanium present in laterites was in a crystalline form was unsuccessful, the present investigation has definitely proved the occurrence of ilmenite, rutile, anatase, sphene, and titaniferous magnetite.

Alkalis.—Felspar, micas, and some of the other silicates present in laterites would account for the alkalis, but it is not certain if all of them are in the form of minerals. The role played by them in the process of lateritization has already been discussed.

Water.—There is a fairly wide range in the amount of water present in laterites. Bauxite accounts for most of it, but some may also be due to the colloids, gibbsite, and hydroxides of iron that may be present.

Colloids.—Rational analysis has afforded evidence of the occurrence of colloidal silica in laterites. Under favourable conditions it forms secondary minerals, else it is left unaltered in the laterite. If so, colloid in laterite is only a transitional stage between the minerals of the original rock and those of the resultant type. These remarks apply as much to the other constituents as to silica.

From the foregoing considerations the relation between laterite and bauxite is clear. Laterite is a rock largely composed of the mineral bauxite together with certain accessories such as silicates, oxides and hydroxides of iron, and oxides of titanium; those constituents that have not altered to give rise to secondary minerals are left as colloids.

VIII. *Spherulitic Structure in Laterites.*

As is the case with several features, no two workers are agreed in their opinions regarding the formation of this structure in laterites. Campbell thinks that spherulitic structure in laterites is only an instance of molecular aggregation, and Fermor (loc. cit., p. 514) allocates this type provisionally to lake deposits, thus doubtfully attributing the agency of water for its formation. According to Lacroix a homogeneous medium with few or no solid elements insusceptible to concretion is the condition necessary for its formation.

[1] D. C. Wysor, Econ. Geol., 1916, vol. 11, p. 44.
[2] L. L. Fermor, Econ. Geol., 1916, vol. 11, p. 689.

The formation of spherulitic structure in laterites, especially those showing a banded structure, afford good instances of Liesegang rings. According to Freundlich [1] the formation of these rings depends on the velocity of formation of a nucleus and the coagulation velocity of the gel, and for satisfactory results a small amount of impurity is desirable. With these conditions may be included the amount of concentration of the constituents of the mixed colloid. Now supposing there is a mixed

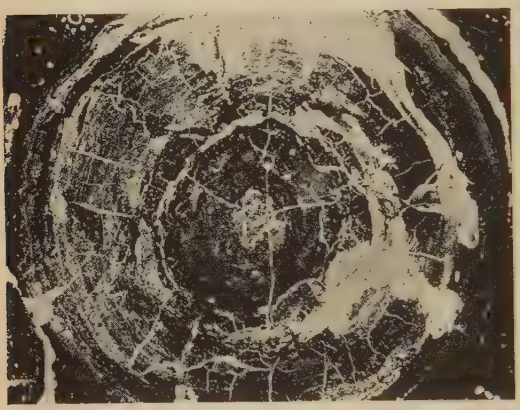

Fig. 5. Banded spherule in laterite showing concentric and radial cracks. Samnapur, India. ×11.

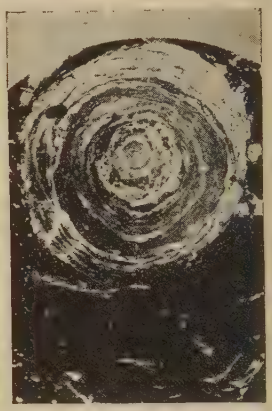

Fig. 6. Spherule in laterite showing concentrically banded structure and closely cemented by matrix. Ejuanema, Gold Coast. ×11.

colloid consisting of two constituents, the one less stable in the colloidal state would form a ring round a nucleus, say, an unaltered mineral of the original rock. The removal of a portion of the less stable colloid to form the first ring will increase the concentration and consequently the coagulation velocity of the second colloid in the mixture and thus enable it to form a second ring. The concentration and the coagulation of the less stable colloid that formed the first ring would now have increased, resulting in the formation of a third ring. In this manner spherules with a banded structure would be formed (fig. 6). The presence in the colloid of a third constituent of the rock would serve the function of the desired impurity and hasten the formation of this structure. The

[1] H. Freundlich, Colloidal and capillary chemistry (1923), English translation, 1927, p. 733.

formation of banded structure would, as pointed out by Lindgren[1], be accompanied by expulsion of water and reduction of volume, resulting in concentric and radial cracks (fig. 5) in which secondary gibbsite is sometimes formed.

The two sets of chemical analyses given below show the difference in composition between the spherules and their respective matrices in two specimens of laterites.

	Unlocalized (no. 46). (Analysed by T. V. M. Rao.)		Maddox, Georgia, U.S.A.[2]	
	Spherule.	Matrix.	Spherule.	Matrix.
SiO_2	1·01	0·64	3·74	0·62
Al_2O_3	54·78	62·91	52·36	64·91
Fe_2O_3	4·08	1·92	0·76	0·28
MgO	0·80	nil	nil	nil
CaO	0·79	0·68	nil	nil
Na_2O	0·27	0·36	nil	nil
K_2O	0·12	0·02	nil	nil
$H_2O(+)$	27·36	27·53	33·17	33·00
$H_2O(-110°\,C.)$	—	—	0·20	0·53
TiO_2	11·46	5·97	9·70	1·05
Total	100·67	100·03	99·93	100·39

The percentages of all constituents except those of alumina are greater in the spherules than in the matrices.

During the description of specimens of laterites it was pointed out that in some of the specimens the spherules were easily detachable intact from the matrix, while in others this was not possible. In the absence of any explanation for this feature, the following suggestion might be offered. If after the lateritization of the rock the spherules were to form and consolidate before the matrix, they would be easily detachable intact. But if, on the other hand, the matrix and the spherules consolidated simultaneously, the soft outermost walls of the spherules would become confluent with the matrix and when the specimen becomes indurated would be undetachable intact.

IX. *Summary and Conclusions.*

The chief points emerging from this paper are the following:

(1) The process of lateritization consists of the action of alkali carbonates on the aluminium silicates of rocks, when hydrated aluminium

[1] W. Lindgren, Bull. Geol. Soc. Amer., 1925, vol. 36, p. 254.

[2] Vide T. L. Watson, Amer. Geologist, 1901, vol. 28, p. 25, for this set of analyses.

carbonate is formed; this compound being unstable breaks down into hydrated aluminium oxide, which is deposited in the form of bauxite. This, together with the undecomposed minerals of the rock, forms laterites.

(2) Bauxite is a definite mineral having a composition corresponding to a dihydrate of alumina.

(3) The gibbsite present in laterites is of secondary origin formed by hydration of bauxite.

(4) Diaspore never occurs in laterites, as mere conditions of lateritization are not sufficient for its formation.

(5) Felspar, micas, kyanite, tourmaline, haematite, magnetite, limonite, pyrite, ilmenite, rutile, anatase, and sphene, some of primary and others of secondary origin, have been definitely found to occur in laterites.

X. *Acknowledgements.*

Finally, the writer wishes to express his indebtedness to all those from whom he received assistance in the course of this work. He is thankful to the Directors of the Imperial Institute, the Geological Surveys of India and of the Gold Coast, and of the Department of Industries of Travancore, and to the Trustees of the British Museum for presenting the specimens necessary for the above work.

He wishes to express his sincere thanks to Prof. W. W. Watts for affording all necessary facilities for carrying out this work. Drs. J. W. Evans and H. F. Harwood also deserve his best thanks, the former for discussing the results of the experimental work and the latter for supervising the chemical part of the work in this paper. Dr. A. Brammall, Dr. P. K. Ghosh, Mr. G. S. Sweeting, and Mr. John Furniss are also to be thanked for assistance either in the field or in the laboratory.

A simple and accurate constant-volume pyknometer for specific gravity determinations.

By H. V. Ellsworth, M.A., Ph.D.
Geological Survey of Canada, Ottawa.

[Read January 17, 1928.]

EXPERIENCE with the usual types of glass pyknometers long ago convinced the writer that these instruments as ordinarily used are subject to considerable errors and may be quite unreliable when dealing with small quantities of material. It is true there are forms [1] intended to be used in conjunction with a very precisely regulated water-bath which are capable of giving results of high accuracy, but this method of determination at constant temperature involves too much time and trouble for routine mineralogical work. But no matter what the design of glass pyknometers, and their variety is legion, in actual practice they suffer in common from the defects of the material of which they are constructed.

The heavy-solution method is inconvenient ; it cannot be used for the heavier materials and there is often danger of contaminating the material which may be intended for analysis. There is a real need for a simple method capable of giving consistently accurate results—particularly on small specimens and powdered material—with a minimum expenditure of time and attention.

To fill this need the silica-glass pyknometer here described was designed by the writer some eight years ago, and has since been in constant use with very gratifying results. The design was carefully worked out in an endeavour to secure the following characteristics:

1. Not more than 0·0001 c.c. change in volume of the bottle for ordinary variations of room temperature (in Canada). This called for fused silica construction and a volume not exceeding 10 c.c.

2. Constant depth of seating of stopper. This again called for silica-

[1] A. E. H. Tutton, Crystallography and practical crystal measurement, 1911, p. 519, et seq. J. Johnston and L. H. Adams, Journ. Amer. Chem. Soc., 1912, vol. 34, p. 566.

glass, with its low coefficient of expansion, fine grinding and accurate fit of stopper, and a stopper having not too acute an angle.

3. Stopper with capillary side tube graduated at intervals of one-half centimetre and of uniform bore such that the capillary column of water weighs approximately one milligram per centimetre at 20°, so that fine weighing can be done entirely by the balance-rider with the unaided eye. The meniscus of such a column can be seen readily through the balance-case at a distance of 12 to 18 inches. The graduations on the side tube

Fig. 1. Photograph showing pyknometer and accessories.
(About one-third actual size.)

extend completely around the tube to avoid parallax in reading the meniscus.

4. Perfect over-all contact between stopper and bottle with no groove at the top or other pockets or depressions to retain water and produce irregularities. This is achieved by grinding and subsequently fire polishing the top of bottle and stopper, and by special attention to the grinding of stopper.

5. Stability, with strength and rigidity, to withstand vacuum and heating.

6. Suitable ring on neck so that it may be handled conveniently by means of tongs.

The result of these considerations is the instrument shown in fig. 1. It is made of transparent fused silica, has a volume of almost exactly 10 c.c., and weighs about 10 grams. Approximate dimensions in millimetres are indicated on the sketch (fig. 2).

The anticipation of superior performance has been fully realized. The pyknometer can be heated to 100°, subjected to vacuum, and cooled without changing in apparent capacity more than 0·0002 c.c. at temperatures between 18° and 25°, the apparent change including also all errors

of filling, weighing, and temperature determination, and these results can be repeated year after year.

The method of specific gravity determination using this pyknometer is based on the assumption that minerals will suffer only a negligible change in volume between, say, 18° to 22°, as compared to their volume at 20°, the standard temperature; so that sufficiently accurate results may be obtained by using a pyknometer of constant volume at these temperatures.

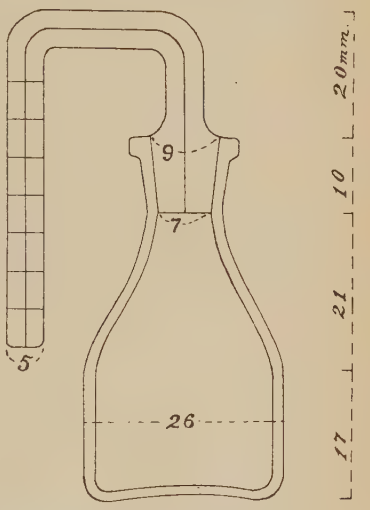

FIG. 2. Sketch showing dimensions of pyknometer. (Actual size.)

In use, the pyknometer is first calibrated once for all by determining its volume at room temperature with the meniscus of the capillary column of liquid at the various graduations on the side tube. This is done as follows. After weighing clean and dry, it is about half filled with water and the water boiled. It is then completely filled with boiled water and the stopper inserted quickly so that no air is entrapped and water rises through and passes out of the capillary side tube. The free end of the side tube with a drop of water adhering is inserted to a depth of $\frac{1}{8}$ inch in water contained in a small beaker and allowed to stand near the balance until cooled to room temperature. The pyknometer thus will automatically fill with water at room temperature. It is then lifted from the beaker by means of wooden tongs, the wet end of the side tube allowed to dry, and weighing begins. The meniscus in the capillary retreats at a regular rate as water evaporates from the capillary and from around the stopper; so that by using the balance-rider it is very easy to catch the exact weights for the second or third divisions and for each successively to the last of the graduations. Having completed weighing to the last mark, the pyknometer is taken off the balance at once with the pair of wooden tongs at room temperature, the capillary stopper is disconnected, and with a small medicine dropper also at room temperature about 1 c.c. of water is quickly removed. A suitable thermometer is then inserted and the temperature read to at least $\frac{1}{20}°$. Knowing the weight of contained water at the various graduation marks

and the temperature, the volume is calculated from the tables of the Reichsanstalt[1] or of Chappuis.[2] Since the volume is thus derived from the International Tables, it is necessary that the weights used be calibrated against standard weights and that the thermometer should be similarly corrected by reference to the international hydrogen thermometer scale.

Using weights and thermometers corrected by the U.S. Bureau of Standards, the writer has obtained the following values for the capacity of one of these pyknometers :

Date.	Temperature.	Capacity.
1922	19·28°	10·1500 c.c.
1922	20·77	10·1497
1922	22·77	10·1497
1923	18·83	10·1500
1923	21·92	10·1501
1924	24·22	10·1498
1924	22·47	10·1498
	Average	10·14987

These are not selected results, but include every determination made from the time the procedure was first perfected. Since an error of 0·0001 gram in weighing or an error of $\frac{1}{20}°$ in reading the temperature will cause an error in apparent capacity of 0·0001 c.c., it is evident that the results prove the remarkable certainty and uniform performance of the instrument itself. It may be seen that no single result varies more than 0·0002 c.c. from the average and that the 1924 results appear to be practically the true value.

The procedure for a specific gravity determination scarcely needs detailed description, being similar to that used in calibrating for capacity. Knowing the capacity of the pyknometer and the temperature of the water, the weight of water displaced is found from the International Tables. It is always advisable to heat the mineral powder and water in the pyknometer under vacuum. One or two precautions should be noted. In seating the capillary stopper it should be slightly rotated once or twice and finally brought always to the same definitely fixed position of rotation by reference to a permanent mark on the rim of the bottle. This is necessary because the volume may vary slightly for different positions of rotation of the stopper. Such variations may

[1] M. Thiesen, K. Scheel, and H. Diesselhorst, Wiss. Abh. Phys. Techn. Reichsanstalt, Berlin, 1900, vol. 3, p. 69.

[2] P. Chappuis, Travaux et Mémoires du Bureau International des Poids et Mesures, Paris, 1907, vol. 13.

be rendered visible by noting the advance and retreat of the meniscus in the capillary side tube as the stopper is turned.

The medicine dropper is used to remove the amount of water that would be displaced by insertion of the thermometer, so that the water does not overflow the bottle and cause lowering of temperature by evaporation. t can be adjusted in such a way as to remove automatically exactly the right amount of water.

The whole equipment of pyknometer, thermometer, medicine dropper, and wooden tongs should be at room temperature near the balance-case when in use. The temperature of the water in the pyknometer after weighing will ordinarily be a fraction of a degree higher than room temperature, due to radiation from the body of the operator during weighing.

Pyknometers of this design were made of transparent silica-glass by the Silica Syndicate,[1] London, at a moderate cost and satisfactorily fulfilled the specifications in every respect. The fit of the stoppers, however, was improved by grinding with the finest grade of alundum and finally with optical alundum.

Special thermometers were designed to use with the pyknometers. They are 5 mm. diameter, 260 mm. long, and are graduated from 12° to 30° C., each degree occupying a length of 1 cm. on the stem and divided in twentieths, though it is easy to read to the fortieths by the aid of a hand-glass. The thermometers in use by the writer were made by the Precision Instrument Company of Philadelphia and were very satisfactory, tests by the U.S. Bureau of Standards showing almost negligible uniform corrections of one to three hundredths of a degree. These thermometers should be calibrated and tested under the same conditions as when in actual use, i.e. with 1-inch immersion and the remainder of stem in air at room temperature.

Although the method as outlined may seem rather complicated it is really very simple, requires but little actual working time, and for exactness leaves nothing to be desired.

[1] Now the Thermal Syndicate, Limited, Neptune Bank, Wallsend-on-Tyne.

On the biotite-bearing greenstones and on a rhyolitic pumice in the metamorphic aureole of the Falmouth granite.

By P. K. Ghosh, M.Sc. (Calcutta), Ph.D. (London),
Research student, Imperial College of Science and Technology, London.

[Communicated by Prof. W. W. Watts, F.R.S.; read November 1, 1927.]

I. *Biotite-bearing Greenstones.*

IN the metamorphic aureole of the Falmouth granite, the greenstones which are largely referable to epidiorites form an important and interesting assemblage of rocks. These are lower Palaeozoic in age and are pre-granite and have suffered from metamorphism as an effect of the granite-intrusion in post-Carboniferous times.

The chief mineral constituents, viz. hornblende and plagioclase, are quite normal for a rock of this nature except that the former is clearly a derivative of augite, many relics of which are still preserved; among the most important accessory minerals are biotite, chlorite, epidote, iron-ores, quartz, augite, axinite, and garnet.[1] One may pass over some of the accessories as being quite usual, being partly primary and partly secondary in origin, but biotite is one of those the presence of which requires to be specially explained.

The Geological Survey hinted that its origin was probably due to contact-metamorphism by the granite.[2] On the other hand, a recent study of the exposures on the north-east side of the granite (near Burnt House) leads the writer to adopt a different view. There is no doubt that a certain amount of reconstruction of the structural and mineralogical features of the greenstones has been brought about by the granite-intrusion, but no evidence could be found that the mineral had originated from any other pre-existing constituent of the greenstone. The field evidence itself strongly suggested that the genesis of this mineral was due to the contamination of the basic magma by the pelitic suite (slates) into

[1] On the geology of Falmouth and Camborne. Mem. Geol. Survey of England and Wales, 1906, p. 41.

[2] Op. cit., p. 43.

which it was intruded and which was largely disrupted and assimilated by it, leaving behind certain altered residues (biotite-hornfelses) which are all that remain of the sedimentary inclusions. Where shattering and dispersal of the fragments have been complete the inclusions have disappeared as such, but stray crystals of biotite still remain in the normal mineral assemblage of the greenstones.

The evidences found in the field and under the microscope in favour of this view are given below.

Field characters.—In the quarry, just north of Cosawes Pascoe, there is a good exposure of epidiorite; its contact with the strongly altered slates is also observed in places. The rock is sheared and sometimes schistose; the colour is preponderatingly dark green. But what arrests attention in this general scheme of dark green colour is the occurrence of definite buff and bronze-coloured zones, streaks, and patches which are apparently composed chiefly of biotite; these are schistose, and their schistosity may not be parallel to that of the greenstone. Bridging these typically xenolithic aggregates of biotite on the one hand and the normal epidioritic rock on the other, there are gradations in which the proportion of biotite gradually falls; and it is not unusual to find specimens showing beautiful lit-par-lit injections of the greenstone material along the planes of schistosity of the biotitic patches grading on to specimens where only a few specks of biotite may be discernible.

Microscopical evidence.—Microscopical examination confirms the xenolithic nature of the biotitic patches. In the normal epidiorite, which is of a more or less intergranular texture and composed of augite and its decomposition products (actinolite, chlorite, &c.), plagioclase in large patches (mostly decomposed), sphene, iron-ores, &c., there are observed sheaf-like foliated aggregates of yellowish-brown crystals of biotite. These biotite clots are very often interspersed with small, clear and rounded grains of plagioclase and a little quartz. The texture of the biotitic patches (including biotite, plagioclase, quartz, and an abundant dark, opaque material, probably graphite), which recalls that of biotite-hornfelses in granites, at once marks them out as distinct from the rest of the rock; their boundaries are quite sharp and end against the usual minerals of the epidiorite. There may be little or none of the epidioritic or doleritic minerals in these patches; but when they are present, as is generally the case, crystals of augite or its derivative hornblende, and large decomposed felspars occur dispersed at all angles to the foliation planes of biotite, and it is evident that the whole assemblage is a complex mixture of two distinct types of rocks, viz. the

doleritic magma on the one hand and the biotite-hornfels on the other. In addition to these types where both varieties of rocks may be distinguished by their distinct textural and mineral assemblages, there also occur types in which they are represented mainly by biotite on the one hand and pyroxene or amphibole on the other. In others, when the amount of biotite falls very low its xenolithic nature is entirely lost, the mineral having the aspect of a normal constituent of the rock; these cases are to be explained as due to the extreme shattering and dispersal of the constituents of the hornfelsed material.

The later crystallization of the doleritic material under a condition different from that of the biotite-hornfels is also brought out by the complete indifference of the behaviour of the augite or hornblende crystals of the epidiorite with respect to the planes of schistosity in the biotite patches. Thus the elongation of the ferromagnesian minerals may not only be at a different angle to that of the schistosity of the biotite but it is not unusual to find aggregates of the biotite heaped into an arch where they are in contact with augite or hornblende; individual crystals of the latter may be seen cutting through the biotitic zones; and, though rarely, veins of the epidioritic material may be seen intersecting the biotite folia. These observations alone raise a serious objection to the view of the derivation of the biotite from the greenstone material itself, presumably from its augite and hornblende; if that had been so, the textural relations would have revealed biotite to be younger than and unaffected by augite and hornblende crystals of the greenstone.

Regarding the genesis of the biotite-hornfels, it seems likely that the pressure and temperature conditions prevailing at the time of intrusion of the doleritic magma into the shale rock converted it into a hornfels in which biotite predominated. The fragments of the country-rock which were stoped by the magma were shattered and dispersed throughout its body, and on further shattering gave rise to the small patches and streaks and, finally, to the isolated crystals of biotite in the basic magma. For lack of chemical investigations it is as yet too early to say if the original sedimentary fragments were acted on in a way similar to the slate fragments in granite, or even if there was any interchange of material at all—issues that might be followed up subsequently.

II. *Rhyolitic pumice.*

The occurrence of rhyolite is interesting as being perhaps the first recorded example of acid hypocrystalline rocks in this region.[1] It

[1] Op. cit., p. 41.

occurs in the metamorphic aureole of the granite, to the south of the Burncoose greenstone mass on the north-eastern side of the granite. Unfortunately, its field-relations are extremely obscure. It shows evidences of metamorphism which may be ascribed to the granite-intrusion. But whether it represents the acid extrusive phase of igneous activity of which the adjacent mass of greenstones is the basic intrusive counterpart, it is difficult to say. It could be traced intermittently over an area of about $\frac{1}{3}$ by $\frac{1}{8}$ mile mixed up with slate and epidiorite fragments about one-sixth of a mile to the north-east of Gilly's farm-house.

Megascopic characters.—In hand-specimens the rock is greenish, purplish, and violet; when decomposed it is buff. It is composed of porphyritic crystals of much weathered felspars and quartz; the former is at times large; both are greatly fractured; these are embedded in an opaque, greenish, or purplish groundmass which is full of holes that impart a scoriaceous and slaggy character to the rock. Flow-structure is sometimes noticeable in the arrangement of the gas-holes and bands differing in colour.

Microscopical characters.—Porphyritic felspars, which are orthoclase, are thoroughly decomposed, fractured, and granulated. The quartz is full of inclusions; it is granulated and shows undulose extinction; sometimes the fractured parts of quartz are cemented by a glassy base. The phenocrysts are embedded in an abundant glassy base which is full of numerous gas-holes, generally empty. The groundmass is colourless in places, but is generally of a dark tone. Its transparency also varies, chiefly due to the inclusions of an opaque dust. Cubical crystals of pyrite, shreds of brown hornblende, and plumose or acicular crystallites are also present in the groundmass. There may also be present minute laths of felspar recalling the trachytic texture. Some dark, opaque bodies which are quite angular and irregularly notched occur in the groundmass—these perhaps represent some xenolithic material.

Some cordierite also occurs showing sector-twinning; the crystals are colourless, more or less rounded in appearance, and are very small. The gas-holes are generally empty, but a little chalcedony and tridymite (?) have also been noticed in them.

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MINERALOGICAL MAGAZINE

CONTENTS OF NO. 120

(March, 1928)

	PAGE
Proceedings of the Mineralogical Society	xlvii
L. J. Spencer: Potarite, a new mineral discovered by the late Sir John Harrison in British Guiana	397
T. V. M. Rao: A study of bauxite	407
H. V. Ellsworth: A simple and accurate constant-volume pyknometer for specific gravity determinations	431
P. K. Ghosh: On the biotite-bearing greenstones and on a rhyolitic pumice in the metamorphic aureole of the Falmouth granite	436

MINERALOGICAL ABSTRACTS

(Vol. 3, No. 9, Pages 413–460)

Notices of Books (p. 413).—Geometrical Crystallography (p. 414).—Crystal-optics (p. 419).—X-rays and Crystal-structure (p. 423).—Precious stones (p. 436).—Topographical Mineralogy (p. 442).—Miscellaneous (p. 447).

Anderson, C. A. 456
Astbury, W. T. 435
Auer, J. 443
Barth, T. 426
Barthoux, J. 444
Bauer, L. H. 453
Becke, F. 414, 419
Beckenkamp, J. 417
Berman, H. 453
Böhm, J. 430
Bozorth, R. M. 429
Bracewell, S. 437
Bragg, W. H. 435
Brammall, A. 422
Brauns, R. 441
Bräutigam, F. 420
Brown, G. B. 432
Bruce, E. L. 454
Burbank, W. S. 454
Chirva, E. F. 447
Chirvinsky, P. N. 443
Chudoba, K. 419–20
Clinton, H. G. 457
Coleman, A. P. 457
Conolly, H. J. C. 438
Cork, J. M. 431
Cross, W. 445
Davidson, S. C. 440
Dehlinger, U. 425, 429
De Lury, J. S. 445
Dolivo-Dobrovolsky, V. V. 447
Doll, C. G. 446
Eakle, A. S. 446
Emerson, O. H. 459
Eppler, W. F. 437
Evans, E. J. 424
Evans, J. W. 418
Ferraz, J. B. de A. 446
Finch, R. H. 459
Finkelnburg, W. 422
Fisher, L. W. 446
Flink, G. 442
Forster, R. 424, 430
Foshag, W. F. 452, 457
Frankenfield, J. S. 460
Friauf, J. B. 424
Fromme, J. 442
Fuller, M. B. 455
Gillson, J. L. 455
Goodtzov, N. 425
Goranson, R. W. 455
Gossner, B. 433–4
Gottfried, C. 426, 430, 433–4
Haase, M. 421–2
Havighurst, R. J. 427
Hawkins, A. C. 454, 460
Haworth, F. E. 429
Heide, F. 431
Hendricks, S. B. 427, 432, 436
Hentschel, H. 428
Hermann, C. 425
Hess, F. L. 452
Hibsch, J. E. 441
Hoog, A. 426
Huggins, M. L. 427
Humphrey, W. A. 488
Hylleraas, E. A. 429
Iimori, S. 449
Jaeger, F. M. 424
Ježek, B. 439, 443
Johnsen, A. 437
Johnston, W. D. 459
Jones, W. M. 424
Jones, W. R. 422
Jong, W. F. de 426, 430
Jung, H. 423
Kargin, W. 440
Kellner, G. J. 440
Kryzhanovsky, V. I. 439
Kunz, G. F. 436
Kurbatov, J. 440
Kurdyumov, G. 425
Landon, R. E. 456
Larsen, E. S. 451–2
Laski, G. 422
Laue, M. 423
Lausen, C. 456
Light, M. 454
Linck, G. 451
Little, J. M. 446
Lonsdale, J. T. 454
Lunde, G. 426
MacCarthy, G. R. 459
McCutcheon, T. P. 432
Machatschki, F. 426
Magill, P. L. 427
Mark, H. 430, 435–6
Matsuura, J. 450
Maufe, H. B. 445
Mehner, H. 435
Michel, H. 440–1
Mitchiner, J. H. 438
Morgan, G. T. 435
Müller, J. H. 428
Mussgnug, F. 433–4
Myers, W. M. 458
Niggli, P. 415
Noethling, W. 436
Ooé, Z. 425
Ott, H. 423
Palache, C. 455
Putnam, P. C. 460
Puzyrev, G. L. 421
Rabinowitsch, B. 419
Reagan, A. B. 441
Ries, H. 413
Rinne, F. 415, 419, 428, 451
Roberts, E. J. 460
Roccati, A. 446
Rode, E. Y. 447
Rogers, A. F. 419
Rösch, S. 421, 437
Rose, H. 437
Sasaki, J. 450
Savul, M. 450
Schairer, J. F. 456
Schiebold, E. 416
Schoep, A. 460
Schwartz, G. M. 458
Selchow, D. H. 460
Selyakov, N. 425
Sen, J. 415
Shannon, E. V. 445–6, 453, 458–9
Short, M. N. 453
Slavík, F. 442
Smirnov, S. S. 448
Spencer, L. J. 439
Stearns, H. T. 454
Steiger, G. 451
Stockwell, C. H. 433
Stürenburg, M. 421
Sushchinsky, P. P. 421
Swartz, J. H. 418
Takebe, T. 449
Tarr, W. A. 453
Terpstra, P. 418, 424
Tertsch, H. 423
Thilo, F. 428
Thomassen, L. 460
Tokody, L. 429
Tschirwinsky, P. N. 443
Ulrich, F. 460
Vasser, H. E. 435
Vegard, L. 431
Vendl, M. 460
Warren, C. H. 460
Weissenberg, K. 419, 436
West, J. 432
Westenbrink, H. G. K. 424
Wherry, E. T. 418, 453
Whitlock, H. P. 437
Winchell, A. N. 413, 423, 457
Winchell, N. H. 413
Wyckoff, R. W. G. 428, 432
Yamaguchi, Y. 449
Yoshimura, J. 448–9
Zachariasen, W. 427, 432, 435

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